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Development of a multivariate analytical system to identify lameness in dairy cows

Development of a multivariate analytical system to identify lameness in dairy cows

By

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Abstract

Lameness is a key welfare issue in the dairy industry. With approximately a third of all dairy cows in the UK experiencing lameness at any one time, it poses serious economic losses to the farmer. While advisory tools exist to address the associated risk factors, the problem persists. This project hypothesises two reasons for this: the varied approach to defining the issue, and the tendency for observers to misdiagnose mildly lame cases. As the condition has the potential to cause chronic pain, it is important to identify it early, before lame cows' experience long-term suffering. This project was formed of two complimentary studies. The first study used historical data on dairy cows' physiology, to develop a new multivariate analytical system; while the second used interviews to identify gaps in the industry's understanding of lameness, and any variables that could be used to develop the scoring method. For the first study; mobility score, milk yield, body condition score, fertility (either measured by lactation number or parity) and somatic cell count, were used to determine the severity of lameness. The variables were normalised and combined (using MATLAB) via post-classification fusion, to generate an overall lameness score. An individual's result was presented as a line on a histogram, so their severity of lameness, along with the distribution among the herd, could be identified. For the second study, eight experts were interviewed (two academics and six qualified veterinarians) to gain their understanding of chronic lameness and any cow variables of interest. The interviews were transcribed and analysed using NVivo. The results from the consultations will support the development of the scoring system in the future, so researchers will be better able to detect lameness before it becomes a chronic problem, greatly improving the chances of full recovery.

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I would like to extend my thanks to all of the participants who took time out of their busy schedules to be interviewed. Their contribution was very important in understanding the current gaps in our knowledge of lameness.

Author’s Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

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Introduction

1.1. Background

As the fourth largest food group – behind carbohydrates, protein, and fruits and vegetables (Public Health England, 2017) – dairy products are globally recognised as a staple part of human diets. There is a widely held view that milk is necessary for growth; in the United States for example, it is recommended that children consume three cups of dairy milk per day (USDA, 2017). This view has led to farmers coming under increasing pressure to produce high volumes of milk, at the lowest price possible. The UK is the tenth-largest producer of milk in the world and the third-largest producer in the EU (Baker and Bate, 2016); yet the number of dairy cows in the UK has fallen by 27% since 1996 (Baker and Bate, 2016) alongside a paradoxical increase in milk yield, which has put increasing demands on dairy cows, often at the price of their welfare.

1.2. Definition of animal welfare

The definition of animal welfare is something that keeps evolving (von Keyserlingk and Weary, 2017). In the simplest sense, animal welfare can be defined as the wellbeing of an individual as it attempts to cope with its environment (Broom, 1986). This definition incorporates both physical and mental state. This is an important distinction as in 2009, animals were formally recognised as sentient beings, in the amendment of Article 6b of the Treaty of Lisbon (The Member States, 2007). However, the sentience of animals was acknowledged much earlier in 1965 in the Brambell Report (1965), a report that subsequently led the Farm Animal Welfare Council (1993) to develop the five freedoms, listed below:

1. Freedom from hunger and thirst
2. Freedom from discomfort
3. Freedom from pain, injury, and disease
4. Freedom to express normal behaviour
5. Freedom from fear and distress

The physiological necessities and the environmental conditions, represented by the first four freedoms, interact and affect the fifth freedom, the animal's mental state

(Mellor and Beausoleil, 2015). In their natural environment, animals make decisions to avoid the situations that will compromise their health, however, in domesticated systems, the animal's mental and physical wellbeing is determined by the choices made by the farmer (Harrison, 1964; Mellor and Beausoleil, 2015). Farmers therefore, must consider these interactions when managing their livestock.

Although the five freedoms model is useful at identifying the basic needs of an animal, it fails to acknowledge the need to be free from a compromised welfare state. Therefore, when defining what is "good" animal welfare, this framework is restricted to what is "acceptable" (Mellor and Reid, 1994; Farm Animal Welfare Council, 2009b). In 1994, Mellor and Reid adapted the freedoms into 'domains' where the extent of potential welfare compromise was represented by a five-step, non-numerical scale – O, A, B, C, X; from no welfare compromise (O) to a very severe welfare compromise (X). Although the five domains expanded the five freedoms by evaluating the severity of welfare compromise, they did not expand the number of negative effects (Mellor and Beausoleil, 2015). As our understanding of animals' experience of distress has developed, more specific effects were added to the umbrella term "distress" to broaden the capability of welfare assessments to identify possible negative impacts (Mellor, 2012).

While the expansion of the freedoms beneficially directed focus towards avoiding negative experiences, positive welfare effects were still overlooked (Mellor and Beausoleil, 2015). More recently, Mellor and Beausoleil (2015) rectified this oversight by extending the five domains and incorporating welfare enhancement; defined as the interaction between the animal's propensity to engage with its environment, otherwise known as agency, and any resulting positive outcomes. The grading system proposed by Mellor and Beausoleil (2015) looks at three elements:

- Opportunity – the capability for the animal to exercise self-motivated positive behaviour.
- Utilisation – whether the animal acts in the presence of opportunity.
- Welfare enhancement – an element underpinned by opportunity and use.

By combining the two assessments, welfare compromise and enhancement, into one unit, researchers can better understand how negative and positive affects interact, improving our understanding of quality of life (Mellor and Beausoleil, 2015). To build on this research, and our knowledge of animal sentience, future assessment should focus on ensuring welfare enhancement outweighs welfare compromise to provide animals with a life worth living (Farm Animal Welfare Council, 2009a; Mellor and Beausoleil, 2015). While the nature of domestication can mean that pain and distress is unavoidable, especially in the absence of the freedom of choice (Whay and Shearer, 2017; Farm Animal Welfare Council, 2009a), the industry should strive to avoid unnecessary harm. The aim of animal husbandry should be to provide animals with the opportunity to live reasonably natural lives (von Keyserlingk and Weary, 2017).

As milk prices paid to dairy producers in some countries is not regulated, financial fluctuations lead to a loss of opportunity for the cow to experience a natural life, as farmers make cuts to perceived nonessential inputs (Barkema *et al.*, 2015). With increasing milk production often associated with a decrease in cow health (Barkema *et al.*, 2015), welfare problems are common within the dairy industry, placing the positive image of dairy farming under threat (von Keyserlingk and Weary, 2017). The main welfare issues noted by the RSPCA (2017) include lameness, mastitis, cow comfort and the transitions associated with calving. This project will be focusing on dairy cattle lameness, which Ristevski (2017) claims is the most indicative disease of compromised welfare. Associated with a long history of pain (Farm Animal Welfare Council, 2009a), with the potential to develop into a chronic issue, lameness is considered the welfare issue of greatest concern for dairy cattle (Kovacs *et al.*, 2016; Archer *et al.*, 2010).

1.3. The issue of lameness

Lameness is a multifactorial disease predominantly affecting the feet of dairy cows (Leach *et al.*, 2010b; Shearer *et al.*, 2012). It manifests as a painful lesion and inhibits the mobility of the cow (Cramer *et al.*, 2008). Lameness is a disease of global significance, with the average prevalence worldwide estimated to be 25% (Cook, 2016). Although the prevalence varies between farms, in the UK, the estimated prevalence of lameness is 28.2% (Griffiths *et al.*, 2018).

Lameness is an issue of importance both economically and ethically (Mertens *et al.*, 2012). It can be an acute or chronic problem and one case can have a duration of up to 135 days (Whay, 2002). It particularly impacts the higher yielding cows (Green *et al.*, 2002; Ristevski *et al.*, 2017), reducing a cow's productivity (Green *et al.*, 2002) and fertility (Melendez *et al.*, 2003); and as such is associated with substantial economic losses for the farmer (Cramer *et al.*, 2008; Kossaibati and Esslemont, 1997). In a study by Amory et al. (2008) the two main lesions of lameness, sole ulcer and white line disease, were calculated to cause milk losses equal to £91 and £59 respectively, or 570kg and 370kg in milk yield. In severe cases, sole ulcers can also lead to reduced longevity and premature culling (Booth *et al.*, 2004; Charfeddine and Perez-Cabal, 2017). In 2009, Wilshire and Bell estimated the average cost of lameness per affected cow as £323.47, with associated increases in culling and lowered fertility accounting for a large portion of the cost (Kossaibati and Esslemont, 1997).

Although lameness presents a serious issue in terms of farm profitability and animal welfare, it is not as economically important as other welfare concerns. As the cow can be sold live at the end of lactation, provided they are lameness free at this point, the loss experienced by the farmer can be mitigated (Orpin and Esslemont, 2010). The difficulty in calculating the economic loss, in comparison to other bovine diseases, contributes to the lack of research into lameness management. Historically, greater attention has been directed towards diseases with zoonotic potential, or towards those that can be treated pharmaceutically (Bicalho and Oikonomou, 2013). This is confirmed by a literature search of the United States National Library of Medicine (www.ncbi.nlm.nih.gov/pubmed/). Using the search term "bovine lameness", on the 6th November 2017, 1,200 papers were returned. In comparison, when "bovine mastitis" was inputted into the search, 7,960 papers were returned. As lameness poses no threat to human health, and in certain cases is unresponsive to medical treatment, the necessary scientific research has lacked funding.

Fortunately, as more animal activists and consumers have become aware of lameness (Bomzon, 2011; Bicalho and Oikonomou, 2013; Kossaibati and Esslemont, 1997), and as lameness research is increasingly supported by levy boards, we have seen a shift in the amount of research conducted. One project that recently received a large amount of charitable funding was the Healthy Feet Project (2017), which officially launched in 2011. This project used a social marketing approach to promote actions aimed at reducing lameness prevalence (Main and Whay, 2010). Drawing upon existing knowledge of risk factors, this project focused on motivating farmers to overcome their perceived barriers to lameness management (Main and Whay, 2010). The farms that received support throughout the monitoring process showed the greatest reductions in lameness prevalence, highlighting how a structured social marketing approach is a promising solution (Main *et al.*, 2012). Since the project began it has been taken over by the levy board, AHDB Dairy (2017) who continue to offer support to farmers in developing action plans. This marks a positive step in the field of lameness research and with this foundation of support, and the growth in technical understanding (Leach *et al.*, 2010a), it is imperative to take advantage of this positive momentum. The industry must look more specifically at the way in which the disease manifests and develops, so that when farmers do act, their treatment is effective.

1.3.1. The anatomy of the bovine foot

Before the manifestation of lameness is discussed, it is important to outline the anatomy of the foot. A cow's hoof, which is divided into two claws, carries the weight of the animal and provides protection to the internal system (Hoblet and Weiss, 2001; Grist, 2008; Raven, 1989). In order to meet these two functions, the claw is formed of separate, but interlinking parts (Leach *et al.*, 1997). The main components and their individual functions will be briefly discussed.

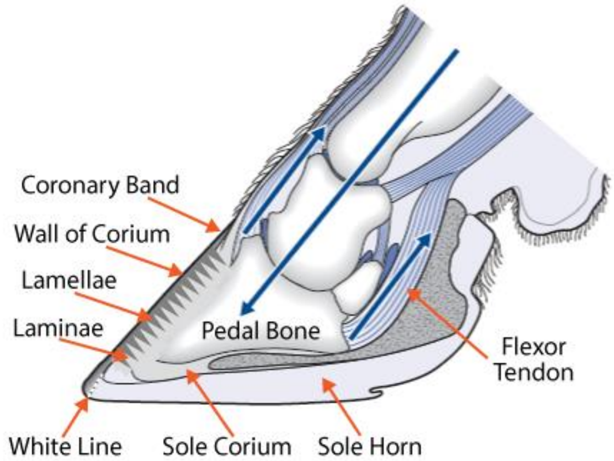

Figure 1: A figure from Dairy Cattle Hoof Health (2008) to show the anatomy of the bovine hoof. As can be seen in the diagram above, the central blue arrow shows the direction of force applied to the sole of the foot. The pedal bone is supported by laminae, preventing it from sinking into the innervated corium.

The individual components of the horn, making up the hoof capsule, differ in level of hardness, going from (in descending order) the outer epidermal wall > sole of the foot > heel > white line (Hoblet and Weiss, 2001). The non-living outer epidermal wall is the hardest part of the claw and serves two functions: protecting the inner tissue from damage; and supporting the cow's body weight with the sole component of the heel (Raven, 1989). It is referred to as the horn of the shoe and is formed from cornified epidermal tissue (Hoblet and Weiss, 2001). As the outer wall is non-living, tissue growth comes from the adjacent living germinal layer, like that of human nails. As the cells are produced they keratinise and push the older cells further towards the surface, where they become cornified and form the horn (Hoblet and Weiss, 2001; Raven, 1989).

The germinal layer, while living, is avascular so its function is supported by the penetration of blood from the barrier layer that separates the internal from the external, known as the corium (Raven, 1989). The corium is the vascularised, outer organ of the foot, damage to which leads to haemorrhage and pain (Raven, 1989). As this organ supplies the epidermis with nutrients and oxygen, disruption of this process starves the outer layers, leading to poor-quality horn production (Hoblet and Weiss, 2001). The transition from horn to corium is represented by the folds of laminae that run longitudinally along the claw (Raven, 1989), of which there are two types: sensitive dermal laminae and insensitive epidermal laminae. These laminae interdigitate and suspend the third phalanx within the hoof capsule.

Attachment of the rigid wall of the horn with the more flexible sole, occurs along the white line (Ossent and Lischer, 1998; Hoblet and Weiss, 2001). This represents the epidermal-dermal junction and is formed of three segments of the wall; terminal horn, laminar horn leaflets and cap horn (Hoblet and Weiss, 2001). As the hoof grows distally, the laminar horn leaflets initially interdigitate with the dermal laminae (Hoblet and Weiss, 2001). The cap and terminal horn are derived from the epidermis of the distal dermal laminae and are the more flexible segments of the white line (Hoblet and Weiss, 2001).

Within the hoof capsule lies the third phalanx of the pedal bone, which is attached by subcutaneous tissue to the corium (Raven, 1989). This attachment only occurs in the anterior portion of the hoof, with the pedal bone free of attachment around the heel and major part of the sole (Raven, 1989). The area free of attachment is supported above the sole by the shock-absorbing digital cushion (Raven, 1989), which is formed of three cylinders of fat and suspended by laminar attachments (Lischer *et al.*, 2002; Newsome *et al.*, 2016). By suspending the pedal bone in the hoof capsule using dermal laminae, the full weight of the cow is not placed on the sensitive corium (Hoblet and Weiss, 2001). The hoof capsule functions to provide the cow with a gait that is both supportive of the cow's body weight, whilst capable of withstanding the concussive forces transferred through the foot during movement (Lischer *et al.*, 2002).

In the UK, the most common causes of lameness are lesions in the claw horn, known as claw horn disruption lesions (CHDL) (Leach *et al.*, 2012; Green *et al.*, 2014; Newsome *et al.*, 2016). The anatomy of the hoof capsule and how this protects the function of the corium is a key factor in the development of CHDLs, and subsequent lameness (Newsome *et al.*, 2016; Raber *et al.*, 2004; Newsome *et al.*, 2017a; Raven, 1989). The lesions are hard to treat, and their aetiologies are complex (Offer *et al.*, 2000), but they can be categorised into three main groups (Wierenga and Peterse, 1987; Sogstad *et al.*, 2005; Leach *et al.*, 2010b):

- Metabolic- associated with asymptomatic lameness, laminitis and lesions.
- Traumatic- stemming from wounds or sprains.

- Infectious- associated with poor hygiene and the presence of infective bacteria.

1.3.2. Metabolic causes of lameness

Most CHDLs are the result of metabolic disorders and traumatic injuries to the sensitive corium that lies adjacent to the hoof's wall (Newsome *et al.*, 2017a; Miguel-Pacheco *et al.*, 2017; Shearer *et al.*, 2013; Ossent and Lischer, 1998). The majority of metabolic lesions originate in the hind limbs, with 65% originating in the outer claw (Murray *et al.*, 1996). These lesions include white line disease, which can be divided into white line haemorrhage and white line separation; sole haemorrhage and sole ulcer (Leach *et al.*, 2012; Green *et al.*, 2014).

Historically laminitis, a degenerative process that impacts the laminar corium (Shearer *et al.*, 2013), was considered an important metabolic cause of lameness. It is a systemic disease associated with ruminal acidosis (Bicalho and Oikonomou, 2013), a condition caused by a diet rich in fermentable carbohydrates (Bramley *et al.*, 2008). While laminitis was hypothesised to cause damage to the corium of the hoof, through the leakage of toxic substances from the rumen (Danscher *et al.*, 2010), the general theory is considered to be less important than previously thought (Danscher *et al.*, 2010; Shearer and van Amstel, 2017). This change in opinion over the last 20 years correlates with the change seen in dairy cow nutrition (Tarlton *et al.*, 2002).

A more widely accepted cause of metabolic lameness is associated with a cow's body condition (Randall *et al.*, 2018), in particular the soft sole tissue – the fatty tissue that supports the distal phalanx, the digital cushion and the corium (Newsome *et al.*, 2017b). In cows with a greater proportion of body fat, the digital cushion is thicker and therefore, has a greater force-dissipating capacity (Newsome *et al.*, 2016). By using a body condition score to measure body fat, researchers have identified a predisposition of cows with losses in body fat to develop CHDLs (Newsome *et al.*, 2017a; Bicalho *et al.*, 2009; Raber *et al.*, 2004). Newsome et al. (2017a) propose a theory for the importance of body condition and how losses can lead to lameness. They hypothesise a temporal association between lameness and body fat, whereby in the presence of a negative energy balance, fat is mobilised from the digital cushion causing it to thin. The thinning of the shock-absorbing pads of the hoof reduces the force-dissipating capacity of the sole and leads to greater force borne by the corium. This leads to haemorrhage, interrupted claw growth and cornification, resulting in a poor-quality horn and lameness.

Another theory considers the changes that occur during the peripartum period and the action of hormones, particularly relaxin and oestrogen, on the integrity of the suspensory apparatus during calving and the onset of lactation (Tarlton *et al.*, 2002; Newsome *et al.*, 2017a; Shearer *et al.*, 2013). As the integrity of the supportive structures is compromised, the third phalanx falls into the sensitive corium, which as described above leads to haemorrhage, poor-quality horn and lameness (Tarlton *et al.*, 2002).

Of the lesions associated with lameness, sole ulcers and white line disease are the most prevalent (Bicalho *et al.*, 2007). White line disease describes the widening of the laminar zone, which may be caused by either; the separation of the dermal-epidermal junction of the hoof capsule wall, as a result of the accumulation of fluid, blood or cell debris; or by the sinkage of the laminae (Ossent and Lischer, 1998). The result is a softer white line that disrupts the firm connection between the sole of the horn and the hoof wall (Ossent and Lischer, 1998; Hoblet and Weiss, 2001).

Sole ulcers and sole haemorrhages have a similar pathology yet appear differently, which has led some to believe a sole haemorrhage to be a milder or earlier presentation of a sole ulcer (Newsome *et al.*, 2017a; Green *et al.*, 2014; Hoblet and Weiss, 2001). Shearer et al. (2012, page 541) define an ulcer as “a full-thickness defect of the epidermis (horn) that exposes the underlying corium”. The shared disease process derives from poor quality horn production and excessive force through the foot, which results in tissue necrosis and eventually prevents horn production completely (Ossent and Lischer, 1998; Newsome *et al.*, 2017a). The “typical spot” is the term given to the most common site of sole ulcer or haemorrhage, directly below the flexor tuberosity of the lateral claw of the hind limb (Hoblet and Weiss, 2001).

1.3.3. Traumatic causes of lameness

Traumatic causes of lameness are associated with direct, external damage to the foot and include foreign body penetration, such as nails, stones or other sharp objects, and fractures of the pedal bone (Newcomer and Chamorro, 2016; Shearer *et al.*, 2013). The prognosis can vary depending on the severity of the insult (Shearer *et al.*, 2013). In severe cases a severe osteitis can develop if contact with the distal phalanx is made, or a predisposition to septic tenosynovitis or arthritis can occur (Shearer *et al.*, 2013; Newcomer and Chamorro, 2016).

1.3.4. Infectious disease as a cause of lameness

Lesions found in the skin, or epidermal wall of the hoof, are often clinical presentations of infectious lameness (Murray *et al.*, 1996). The main diseases include: digital dermatitis, interdigital necrobacillosis, interdigital hyperplasia and interdigital dermatitis (Murray *et al.*, 1996). There is debate over which disease is most important with some studies claiming it is interdigital necrobacillosis (Russell *et al.*, 1982; Newcomer and Chamorro, 2016), while others claim it to be digital dermatitis (Murray *et al.*, 1996).

Interdigital necrobacillosis, otherwise known as foul in the foot, is a bacterial disease defined as a necrotising dermatitis, and is commonly influenced by environmental factors (Alban *et al.*, 1995; Van Metre, 2017). The bacterium, *Fusobacterium necrophorum* has been detected on the hooves of infected cows and is believed to have a key role in the development of the disease (Alban *et al.*, 1995; Bennett *et al.*, 2009). The disease begins in the skin of the interdigital space and progresses along the coronary band (Alban *et al.*, 1995). It manifests as foul-smelling, necrotic cutaneous fissures and swelling of the interdigital space and coronary band; which can lead to the separation of the digits and progressive lameness (Van Metre, 2017).

Digital dermatitis is a disease that commonly affects the epidermal layer of the hoof or skin, around the interdigital space, and can lead to lameness in severe cases (Rodriguez-Lainz *et al.*, 1996; Read and Walker, 1998; Plummer and Krull, 2017). Although the exact aetiology of digital dermatitis is difficult to deduce (Wells *et al.*, 1999), the involvement of spirochetes, in particular the *Treponema* genus, is supported by large amounts of evidence (Evans *et al.*, 2008; Carter *et al.*, 2009). The appearance of the disease depends upon the stage of the lesion, from moist, strawberry-like lesions (Wells *et al.*, 1999), to appearing akin to viral papillomotosis; a similarity that originally gave the disease the name interdigital papillomatosis, before viral involvement was ruled out (Read and Walker, 1998; Wells *et al.*, 1999). It has also been suggested the disease is highly contagious, based on the high levels of incidence within affected herds and the surrounding region (Wells *et al.*, 1999; Read and Walker, 1998). The spread of infectious bacteria increases as the lesion advances (Plummer and Krull, 2017). Similar to foot rot, the environment plays a key role in the progression of the disease, with flooring type and access to pasture acting as important factors in the proliferation of the disease (Wells *et al.*, 1999). The main causative mechanism linking these two environmental features is the exposure of the cow's hoof to moisture (Wells *et al.*, 1999). Cows housed indoors with a concrete flooring are more at risk of poor hoof hygiene through continual moisture, as this softens hooves and provides entry points for environmental bacteria (Wells *et al.*, 1999). Existing lesions can also predispose the cow to digital dermatitis as swelling and separation of the digits can result in exposure to the environment (Plummer and Krull, 2017).

1.3.5. Development and treatment of central sensitisation

The previous sections serve to highlight the complex aetiology of lameness. However, whatever the initial cause, the pathologies all lead to the manifestation of pain, which is of greater concern. It is the potential development of longer term sensitivity to the perception of pain, known as hyperalgesia (Whay *et al.*, 2005) that raises serious animal welfare concerns. Hyperalgesia can take two forms: primary hyperalgesia and secondary hyperalgesia (Coderre *et al.*, 1993). Primary hyperalgesia refers to increased sensitivity at the site of injury, whereas secondary hyperalgesia extends beyond the site of injury and develops into what is known as central sensitisation (Coderre *et al.*, 1993).

When tissue is damaged, an inflammatory response is activated that leads to the production of a number of chemicals, which act to elicit primary hyperalgesia and sensitivity around the site of injury, known as peripheral sensitisation (Anderson and Muir, 2005; Latremoliere and Woolf, 2009). This is an adaptive response that protects the animal from further harm (Anderson and Muir, 2005). When there is a persistent painful stimulus, such as continued walking on a painful lesion, chemical products are released that activate both neuronal and non-neuronal cells (Driessen *et al.*, 2010). It is the response to the production of certain inflammatory mediators, prostaglandins, at the site of injury, which sensitise the peripheral sensory nerve endings (Whay *et al.*, 2005; Hudson *et al.*, 2008). In the presence of persistent pain, the threshold for stimuli activation falls and the responses to subsequent painful stimuli are amplified (Latremoliere and Woolf, 2009), leading to central sensitisation. When this occurs, pain is no longer protective; the sensation is amplified in its duration and intensity, and becomes uncoupled from the presence of a painful stimulus, occurring spontaneously as a result of previously innocuous stimuli (Latremoliere and Woolf, 2009; Woolf, 2011). This maladaptive plasticity can cause cows to experience pain for at least 28 days after the cause of the disease is treated (Whay *et al.*, 2005). This phenomenon is not limited to dairy cattle and is common among other animals (Driessen *et al.*, 2010; Karki *et al.*, 2015), including humans (Latremoliere and Woolf, 2009; Coderre *et al.*, 1993; Costigan *et al.*, 2009; Woolf, 2011).

In most cases, treatment of hypersensitivity is difficult to achieve due to the illusory perception of pain in the absence of a noxious stimuli (Woolf, 2011). Add to this, the subjective experience of pain and the difficulty in determining the individual responses to pain management (Bomzon, 2011) in non-communicative animals, and the issue becomes more complex. The duration of pain, even after treatment (Whay *et al.*, 2005), paired with the evidence that a case of lameness can last up to 135 days (Whay, 2002), presents the potential for lameness to become a chronic problem. Research has shown that treatment with non-steroidal anti-inflammatory drugs (NSAIDs) has little effect on the pain the cow experiences (Laven *et al.*, 2008). Furthermore, the amount of NSAIDs needed relative to the weight of a cow is a cost-limiting factor to their widespread use (Huxley and Whay, 2006). While other research shows some benefits to the use of NSAIDs (Whay *et al.*, 2005; Hudson *et al.*, 2008), there is a consensus for the need for an integrated pain management approach, with the combination of pharmacological and non-pharmacological treatments (Bomzon, 2011).

1.3.6. Risk factors

In association with the many causes of lameness, some of which are discussed above, there are many contributory risk factors, summarised by Hoblet and Weiss (2001) (see Appendix 1). According to Solano et al. (2016) the three most prevalent lesions are sole ulcers, white line disease and digital dermatitis. Associated with these three lesions are risk factors including housing type, access to an exercise area, parity and the presence of other claw horn lesions (Solano *et al.*, 2016).

The environment is a major risk factor for lameness, and consideration of the animal's environmental needs, throughout all life stages needs to be, at minimum, in line with the five freedoms. The environment encompasses everything from foot bathing and trimming skills, to cow behaviour and stocking rates. Farmers need to implement regular claw trimming to manage cleanliness and claw growth (Sadiq *et al.*, 2017). The concrete yard needs to be free of damage and sharp edges, to prevent injuries caused while cows are moving to and from the milking parlour (Barker *et al.*, 2010). As dairy cows often spend a large portion of their day lying down, they need adequate lying space with comfortable bedding that is kept clean and dry; to prevent injury when moving from standing to recumbency, and to prevent the spread of infectious bacteria (Burgstaller *et al.*, 2016). Furthermore, while the association between nutrition and lameness remains under debate, it is the farmer's responsibility to provide the appropriate feed for the life stage of the cow, in order to meet its needs and avoid any adverse health conditions (Cook *et al.*, 2004).

Risk factors associated with the environment can often be managed by the farmer, whereas physiological risk factors are harder to control. These include previous history of lameness (Reader *et al.*, 2011; Randall *et al.*, 2018), age and parturition (Raber *et al.*, 2004); all of which increase the cow's susceptibility to developing lameness in the future. The reoccurrence of lameness, because of a previous insult, was shown by Reader et al. (Reader *et al.*, 2011) through their multistate analysis aimed at identifying the association between a reduced milk yield and lameness. They found that even after treatment, lameness could persist in dairy cows (Reader *et al.*, 2011); a conclusion shared by other studies (Newsome *et al.*, 2017b; Lischer *et al.*, 2002).

Age and parturition increase the susceptibility to lameness due to the self-perpetuating cycle that results from bone growth on the distal phalanx (Newsome *et al.*, 2016). With time, the lateral hind claw bears a greater load, depleting the levels of fat found in the digital cushion (Ossent *et al.*, 1987), with the tougher connective tissue replacing the fat lost (Raber *et al.*, 2004). Building on the association of body condition score and lameness, the thinning of the digital cushion leads to inflammation and trauma to the periosteum, which in turn stimulates bone development on the distal phalanx. This creates cyclical damage, as growth of new bone places more pressure on the corium, causing further inflammation (Newsome *et al.*, 2016). This cycle also adds to the risk of a reoccurring condition.

While physiological factors, such as aging, can't be avoided, the research serves to highlight a group of vulnerable cows that require closer monitoring, to ensure any changes in hoof health are dealt with promptly.

1.4. Diagnosing and treating lameness

Upon review of the literature it is evident there are a plethora of causes and risk factors associated with lameness. However, despite universal acknowledgement of what causes lameness, there is currently disagreement in the way the disease is measured (Guard, 2001). This has led to confusion when it comes to applying a definition, restricting the industry's capacity to effectively treat the disease. By the time impaired mobility has been identified, it is likely the disease has progressed to a chronic stage where effective treatment is less likely. Therefore, before research looks at how the disease can be treated and avoided, there is a need for universal agreement on how lameness is defined and measured, with particular emphasis on identifying when it becomes a chronic problem.

1.4.1. Methods used to measure lameness

One method that demonstrates the confusion surrounding lameness detection and monitoring is the mobility score. It is the most commonly used method among farmers to measure lameness and operates as a robust, structured, subjective system. Identification is based on the visualisation of a limp, as the cow's movement is increasingly impeded by pain (Archer *et al.*, 2010). It is a semi-quantitative measure, which is easy-to-use and understand, with definitions assigned to a numerical scoring system.

With the support of independent, self-regulatory bodies, such as the Register of Mobility Scorers (RoMS) (Register of Mobility Scorers, 2018), the mobility score is a standardised procedure that is inclusive of, and reactive to, the needs of the dairy industry. With the encouragement that scoring is conducted by trained and accredited scorers, organisations are working to ensure the collection and preservation of reliable data. Initiatives, such as RoMS, in partnership with organisations such as AHDB Dairy, strengthen the mobility score by making it a universal method, where data is easily accessible, and criticisms are considered and accounted for.

Table 1: A table to show the different mobility scoring systems used in lameness research. The different scores and corresponding definitions, and the research in which the scoring methods are used.

Research	Mobility score				
(Barker *et al.*, 2010; Horseman *et al.*, 2014; Guard, 2001; Leach *et al.*, 2010a; Leach *et al.*, 2010b; Main *et al.*, 2012; Walker *et al.*, 2010; AHDB Dairy, 2013)	**0** Walks with even weight bearing and rhythm on all four feet, with a flat back. Long, fluid strides possible.	**1** Steps uneven (rhythm or weight bearing) or strides shortened; affected limb or limbs not immediately identifiable.	**2** Uneven weight bearing on a limb that is immediately identifiable and/or obviously shortened strides (usually with an arch to the centre of the back).	**3** Unable to walk as fast as a brisk human pace (cannot keep up with a healthy herd). Lame leg easy to identify-limping; may barely stand on lame leg/s; back arched when standing and walking. Very lame.	
(Sprecher *et al.*, 1997; Kovacs *et al.*, 2016; Thomsen *et al.*, 2008; Bicalho *et al.*, 2009; Passos *et al.*, 2017)	**1** Normal, the cow stands and walks with a level-back posture.	**2** Mildly lame, the cow stands with a level-back posture but develops an arched-back posture while walking, her gait remains normal.	**3** Moderately lame, an arched-back posture is evident both while standing and walking, her gait is affected and is best described as short-striding with one or more limbs.	**4** Lame, an arched-back posture is always evident and gait is best described as one deliberate step at a time, the cow favours one or more limbs/feet.	**5** The cow additionally demonstrates an inability or extreme reluctance to bear weight on one or more of her limbs/feet.

(Whay *et al.*, 2005)	**1** Sound.	**2** Imperfect locomotion.	**3** Mild lameness.	**4** Moderate lameness.	**5** Severe lameness.	**6** As lame as possible while upright.		
(Edwards-Callaway *et al.*, 2017)	**1** Sound, the animal has normal posture and a normal gait.	**2** Moderate lameness: stands well but is noted to favour a limb when walking.	**3** Severe lameness: animal either unable to move or able to move but barely able to bear weight on the affected limb. Signs may also include back arch, poor body condition, head bob, and an inability to flex the lower leg joints.					
(Palmer *et al.*, 2012; Manson and Leaver, 1988a)	**1.0** Minimal abduction/adduction, no unevenness of gait, no tenderness.	**1.5** Slight abduction/adduction, no unevenness or tenderness.	**2.0** Abduction/adduction present, uneven gait, perhaps tender.	**2.5** Abduction/adduction present, uneven gait, tenderness of feet.	**3** Light lameness, not affecting behaviour.	**3.5** Obvious lameness, some difficulty turning, not affecting behaviour.	**4.0** Obvious lameness, difficulty in turning, behaviour pattern affected.	**4.5** Difficulty in walking, behaviour pattern affected.

Although the general premise is frequently used, there are discrepancies between the number of scores used and the definitions assigned to each numerical rating (Shearer *et al.*, 2012). This makes it challenging to assign a universal definition for what a lame, and chronically lame, individual looks like. As shown in Table 1, five scoring systems are described, each using different definitions and increments. This undermines the intended simplicity of the mobility score as clarity on which scoring system is best is lacking.

Alternative research methods use electronic sensors to identify lameness by detecting changes in the cow's behaviour and physiology (Kovacs *et al.*, 2016; Miguel-Pacheco *et al.*, 2016; Alsaaod *et al.*, 2012; de Mol and Woldt, 2001). One study used sensors to monitor the heart rate of dairy cattle to observe the levels of stress they were experiencing, as an indicator of pain (Kovacs *et al.*, 2016); while others monitored lying behaviour and activity, eating and rumination time, as well as yield and temperature of milk (Miguel-Pacheco *et al.*, 2016; Alsaaod *et al.*, 2012; de Mol and Woldt, 2001). One useful sensor that shows particular potential, is the use of force plates to measure the way cows are walking based on the weight distributed among their hooves (Ghotoorlar *et al.*, 2012; Mertens *et al.*, 2012). This would objectively evaluate the movement of the cow, without the influence of human error.

The studies that use electronic sensors provide more objective methods to identify lameness, with the added capability of automatically delivering the results to a tablet or computer. However, they are often an expensive solution, as the sensors require an investment in both technology and expertise (Van De Gucht *et al.*, 2018). Therefore, though these methods may be the best future option for long term monitoring, they are not beneficial to farms with a lower income and as such cannot be beneficial to all cows.

1.4.2. Treating cases of lameness

Once an identification of lameness has been made, a universal treatment of corrective claw trimming, sometimes followed by the application of foot blocks, is used to reduce pain and discomfort (Miguel-Pacheco *et al.*, 2017; Shearer *et al.*, 2013). This addresses the consequence of abscess formation by creating an aerobic environment through the removal of all loose and necrotic horn, preventing the anaerobic bacteria from growing in the enclosed microenvironment they engineer (Shearer *et al.*, 2013). By applying a foot block to the healthy claw, the affected claw can be trimmed lower, as weight bearing is adjusted (Shearer *et al.*, 2013; Raven, 1989).

Trimming can also be used as a measure to prevent a subclinical condition becoming clinical (van der Tol *et al.*, 2004). By controlling claw overgrowth and maintaining good underfoot conditions, trimming shifts the focus of pressure to the strongest part of the hoof, the wall, creating a balance between the medial and lateral claw, preventing excessive force being placed on the softer areas of the foot (van der Tol *et al.*, 2004; Raven, 1989).

Infectious lesions are often easier to treat than metabolic lesions (Offer *et al.*, 2000). Diseases such as interdigital necrobacillosis and digital dermatitis can be treated with the administration of antimicrobials. Interdigital necrobacillosis requires the systemic administration of antimicrobials, such as oxytetracycline, and the removal of all necrotic tissue (Cook and Cutler, 1995; Hernandez *et al.*, 2001). Treatment of digital dermatitis involves the direct application of antimicrobials to the lesion (Plummer and Krull, 2017; Hernandez *et al.*, 2001). As digital dermatitis is infectious, treatment can either target the individual, with a therapeutic intervention of the lesion; or the herd, using a preventative strategy, such as the use of foot baths, to minimise the spread of disease among individuals (Plummer and Krull, 2017).

As already mentioned, lameness can be a reoccurring problem (Green *et al.*, 2014). Consequently, follow-up care is important to reduce the risk of repeated injury. Depending on the severity of the lameness and how extensively mobility is affected, moving cows to areas where the motion of standing up and lying down is less restricted, can be beneficial. Moving cows to pasture for a four-week period has been shown to aid recovery and reduce mobility scores, as it provides a more cushioned surface to stand on (Hernandez-Mendo *et al.*, 2007). If it isn't possible to move cows to pasture, then it is necessary to move them to areas with clean, dry flooring that will prevent slipping, where they are close to the milking parlour, to reduce the amount of walking (Shearer *et al.*, 2013). It is also advantageous that they are regularly monitored and therefore, moving a foot trimming crush nearby can enable convenient and efficient examination (Shearer *et al.*, 2013).

The development of central sensitisation presents a necessity for the efficient diagnosis and treatment of lameness as the condition becomes independent from the original insult. As early treatment improves the chance the cow will return to full health (Miguel-Pacheco *et al.*, 2017; Leach *et al.*, 2012; Whay *et al.*, 2005; Newsome *et al.*, 2016; Clarkson *et al.*, 1996), farm staff need to be aware of the many presentations of lameness, so they can treat the lesion as soon as possible. By understanding the risk factors of lameness, the susceptible cows can be more closely monitored to minimise the likelihood of disease (Bicalho *et al.*, 2009). With the help of nationally implemented policy, farmers must meet the guidelines to maintain good animal welfare and avoid unnecessary, chronic pain.

1.5. Research context and aims

As our understanding of lameness develops, we are beginning to see positive changes with greater industry involvement (Main *et al.*, 2012) and reducing lameness incidence; with prevalence estimates in the UK reducing from 36.8% in 2010 (Barker *et al.*, 2010) to 28.2% in 2018 (Griffiths *et al.*, 2018). However, despite these improvements, as one of the most painful disorders to affect dairy cows, lameness prevalence is still too high (Greenough, 2009).

Furthermore, the industry still lacks a universal definition as to when an acute case becomes chronic, therefore, preventing a clear treatment protocol from being universally disseminated. Take for example two studies looking into chronic lameness, conducted by Thomas et al. (2016) and Blackie et al. (2011). In one study, a cow was identified as chronically lame if two of the three previous mobility scores (when scored fortnightly) were greater than 1 (lame) (Thomas *et al.*, 2016). Whereas the other study identified a chronically lame cow if they had the same mobility score for the previous 3 months (Blackie *et al.*, 2011). This simple comparison of two studies goes to show how each research group approaches chronic lameness differently.

It is necessary to build upon the work done by the Healthy Feet Project, which worked on understanding farmers' motives and actions, to find out how we can best define chronic lameness and how it can be identified early. By understanding the barriers to early identification, we can develop a technique that can be routinely used, which is valuable to decision making (Shearer *et al.*, 2012).

One major barrier to any proposed method is cost. As we have become accustomed to the low price of milk, improvements to animal welfare come at a cost most consumers cannot, or will not, pay; with a correlation seen been willingness to pay and increases in income (Clark *et al.*, 2017). The expectation for a cheap commodity has led to a transition to fewer, but more intensive, production systems, reducing the amount of human-animal interaction (Barron *et al.*, 2008).

To overcome the barrier of cost when monitoring lameness, it is important to use an inexpensive method. The mobility score provides a solution to the requirement for a cost-effective method, however, this method is not without its own barriers. As a result of the mixed approach to lameness identification and the number of scoring systems used, we lack a unanimous understanding of what lameness is (Leach *et al.*, 2010a), and allow subjectivity to play a role. In order for a method to be successful it must be a universally accepted diagnostic that all observers agree on and implement (Leach *et al.*, 2010a).

Another barrier of the mobility score is its questionable definition of lameness. Experimental psychology suggests there is a limit to the number of categories we can judge, around the number seven (Miller, 1956; Deolekar and Morris, 2003). This has led to the assumption that fewer categories will lead to an improvement in inter-observer reliability (Deolekar and Morris, 2003). While this is a valid methodological consideration, it limits the amount of information that is transmitted (Deolekar and Morris, 2003), particularly when other factors have a contributing role in the severity, duration and reoccurrence of lameness. Considering the multifaceted aetiology of the disease, the commonly used mobility score categorises lameness by aggregating different signs into one single complex (Lean *et al.*, 2013). Although this provides a straightforward, reliable diagnostic, it fails to convey specificity in the way the disease presents itself in that individual. Particularly as cows are stoic animals and are known to hide their discomfort (Shearer *et al.*, 2012). By oversimplifying the method of identification, the interlinking factors involved can be overlooked, leading to the possibility of an ineffective treatment protocol that doesn't address the complete picture (Lean *et al.*, 2013; Tadich *et al.*, 2010).

To improve the current mobility score so that it is still inexpensive, thorough, quick to use, and universal among farms and research; this project proposes the expansion of the widely used mobility score to better represent lameness severity. Expanding the capability of the scoring system to include other variables will broaden our understanding of how different forms of lameness manifest, and the how long each case persists for. To achieve this goal, a multivariate analysis will be conducted.

There is extensive research in the field of multivariate analysis and combining data, particularly in biometrics and human disease. From the more simplistic scoring systems, such as the BODE index, used to diagnose chronic obstructive pulmonary disease (Celli *et al.*, 2004), and the classification systems used to diagnose chronic hepatitis (Knodell *et al.*, 1981; Ishak *et al.*, 1995); to the more complex fusion of imaging techniques used in biometrics, Alzheimer's disease and Parkinson's disease research (Anzar and Sathidevi, 2014; Hinrichs *et al.*, 2011; Lei *et al.*, 2016; Ye *et al.*, 2008; Arora *et al.*, 2017). What is clear from the literature is that by combining multiple biometric sources, scientists can alleviate the limitations of one source, to gain a more accurate evaluation of disease state (Hanmandlu *et al.*, 2011). In these instances, the greater amount of information transmitted outweighs the potential influence of increased error.

To highlight the concept behind this project, Parkinson's disease (PD) provides a useful example as it shares multiple similarities with lameness research. Parkinson's disease is a chronic, progressive disorder where current treatment can only mitigate the symptoms, not slow the neurodegeneration. When diagnosing the disease there is a lag between the onset of neurodegeneration and the appearance of motor impairment (Bowman *et al.*, 2016). By the time motor impairment becomes visible, over 50% of the affected neurons have already died (Fearnley and Lees, 1991) and the optimal window for neuroprotection is missed (Bowman, 2016). Therefore, as in the field of lameness research, there is a need to find ways to identify the disease early so effective treatment can be administered to slow, and in the case of lameness halt, the disease. While PD is hallmarked by changes in motor function, there are a range of non-motor symptoms that could be used for identification (Bowman, 2016). The use of non-motor symptoms is further bolstered by combining the variables together to compensate for their individual drawbacks (Arora *et al.*, 2017). By employing data fusion, using different diagnostic tools, there is the potential to identify diseases, such as PD and lameness, before the conditions reach a chronic stage.

As a result of the success seen in human medicine, multivariate analysis is already being used in the field of veterinary science, with promising results for the improvement of lameness diagnosis in dairy cows (Van Hertem *et al.*, 2016; Chapinal *et al.*, 2010; Kamphuis *et al.*, 2013; Van Hertem *et al.*, 2013). In general, these studies use automatic sensors, already present on the farm, to measure aspects of the cow's behaviour and physiology that have been found to be associated with lameness; such as, milk yield, body weight distribution and activity levels (Van Hertem *et al.*, 2016; Chapinal *et al.*, 2010; Kamphuis *et al.*, 2013; Van Hertem *et al.*, 2013). While new technology, such as 3D video recordings (Van Hertem *et al.*, 2016), can improve the detection of lameness, as already mentioned, the cost incurred prevent it from being implemented as a universal method. Therefore, by adapting the use of pre-existing sensors, the need to install additional, often expensive, technology is removed (Kamphuis *et al.*, 2013).

This study aims to draw and build upon previous work to create a categorisation of lameness that represents its varied presentation within a herd. This should address our lack of understanding of when the disease becomes chronic and untreatable. The overarching goal is to improve detection and diagnosis of the disease, with more successful treatment as a result. This project is formed of two complimentary studies; the first study presents an alternative diagnostic approach based on currently available data. The second takes the form of a consultation, to gain the experts' opinion on lameness, what their understanding is of chronic lameness, and what the main indicators are. By conducting two studies, there is a greater scope for implementation of the proposed diagnostic, as the incorporation of the expert consultations will allow future tailoring of the scoring method, to ensure it is fit for purpose.

2. Development of multivariate analytical system

2.1. Introduction

Due to the aforementioned limitations of the currently used mobility score, an alternative diagnostic was developed and tested to see if it offered a potential alternative. As previously mentioned in Section 1.5, the use of multivariate analysis has been found to improve the diagnosis of some chronic diseases in both humans and animals (Arora *et al.*, 2017; Van Hertem *et al.*, 2016). However, veterinary medicine still lags behind the progress made in human disease research as, even though the studies use on farm technology, they only produce a binary output of lame or non-lame (Van Hertem *et al.*, 2016; Chapinal *et al.*, 2010; Kamphuis *et al.*, 2013). While this classification is advantageous to the industry (Van Hertem *et al.*, 2014; Van Hertem *et al.*, 2016), it does not address the difficulty in detecting mildly lame cases (Van Hertem *et al.*, 2016; Van Nuffel *et al.*, 2013), how long they can last for, and the development of central sensitisation. Although there is a possibility that mildly lame cows will self-cure, they are at risk of developing more severe lameness and hyperalgesia (Kamphuis *et al.*, 2013); chronic signs that have been shown to be a lot harder to treat (Thomas *et al.*, 2016). Therefore, it is these cows that need early treatment to prevent further development of the disease (Miguel-Pacheco *et al.*, 2017; Leach *et al.*, 2012; Whay *et al.*, 2005; Newsome *et al.*, 2016).

The method was developed using the theory behind multimodal biometrics. Through the process of normalisation and data fusion, biometrics of different units could be combined to improve the identification of lameness (Jain *et al.*, 2005).

Through a multivariate analysis of several physiological variables, this project used historical and recent data to expand the categorisation of lameness based on its severity to better identify mildly lame individuals. The variables were selected based on their relevance to lameness but also their inclusion on accessible farm records such as InterHerd (www.nmr.co.uk). The variables included were locomotion score, milk yield, lactation or parity, body condition score and somatic cell count. By understanding the subtler presentations of mild lameness, and how this can progress into a long-term problem, we can apply a definition to when the disease becomes chronic.

2.2. Materials and methods

2.2.1. Animals and housing

Prior to data collection, ethical approval was obtained from the Animal Welfare and Ethical Review Body (AWERB) (UIN/17/076) and access to data was approved.

To obtain cow level data, we liaised with two individuals who gave us access to dairy farm data. Both individuals gained ethical approval to modify and send us the data we needed for our project.

One source, which will be referred to as Herd 1, collected data alongside our study, for a period of 3 months. They collected data from a herd of 480 cows, all of which were Holstein Friesians. These cows were housed all year round in cubicles, with rubber mattresses and a concrete yard. The cows were fed a maize ration and were milked 3 times a day using a rotary parlour. As part of another study, the cows were mobility and body condition scored fortnightly by a trained researcher. Once each recording was completed, the data were compiled and sent to us, along with the most recent NMR milk recordings.

The other source, which will be referred to as Herd 2, consisted of historical data of a herd of 200 Holstein Friesian cows, who were housed all year round in mattress cubicles. These cows were robotically milked and fed a total mixed ration (TMR) with additional concentrate to yield in the robots. Mobility scoring and body condition scoring were conducted quite sporadically by different, trained researchers, with a quarter of the herd scored fortnightly, with gaps for holidays. The dataset spanned a period of 10 years.

2.2.2. Data collection

The following variables were chosen to be included in the score based on a review of relevant literature, summarised below:

- Mobility score
- Milk yield
- Lactation
- Body condition score
- Somatic cell count

While the commonly used mobility score has its limitations, the development of a limp is still an important identifier of lameness. It was therefore important to include it in the analysis to provide a well-supported, reliable method. For the purpose of continuity, in this project the AHDB Dairy Mobility Score (2013) was used as it is the score implemented by the Red Tractor Scheme (2017b).

Milk yield is commonly measured using electronic sensors attached to the milking parlour (Van Hertem *et al.*, 2013). Lame cows have been shown to have reduced milk yield, both before and after treatment (Reader *et al.*, 2011; Van Hertem *et al.*, 2013; Archer *et al.*, 2010). It is an important indicator of the transition from subclinical to clinical lameness and was therefore, useful in terms of earlier detection (Van Hertem *et al.*, 2013).

Fertility has an important role in lameness as has previously been discussed. The role of hormonal changes on the suspensory apparatus holds important implications in the development of lesions (Lischer *et al.*, 2002; Tarlton *et al.*, 2002). This particular variable has both a contributory role in the development of lameness and is also impacted by its effects. Reduced fertility and breeding activity have been reported in lame cows, presenting economic consequences to the farmer (Melendez *et al.*, 2003; Newcomer and Chamorro, 2016; Lucey *et al.*, 1986; Archer *et al.*, 2010). While parity and lactation do not measure fertility directly, they do reflect the associated changes seen over the course of a dairy cow's productive lifespan (Offer *et al.*, 2000). As parity represents the number of pregnancies a cow has successfully carried, and as lactation is the associated consequence of calving, they are both useful, quantitative measures of the general fertility of the individual.

Body condition score (BCS) can be observed by veterinarians and farm staff in a similar way to locomotion. Edmonson et al. (1989) described a 5-point score (Appendix 2), which has been simplified by the Red Tractor Assurance Scheme (2017a). As discussed in Section 1.3.2. and 1.3.5. body condition score is a well-supported risk factor associated with lameness and therefore, provided an important insight into the severity of the disease and how a cow's condition changes with time.

Somatic cell count (SCC) is a less supported indicator of lameness, however, there is evidence suggesting a relationship between lameness and a higher somatic cell count (Zhang *et al.*, 2015). This was measured in the milking parlour, alongside milk yield.

The raw data was sent in an Excel spreadsheet by both sources. The relevant data was then compiled; Herd 2 was organised by month to compensate for the sporadic mobility and body condition scoring, whereas Herd 1 was organised fortnightly. The cows that did not have data for all the five required variables were removed, as they would not be compatible with the MATLAB code. As BCS, milk yield and mobility score were recorded fortnightly for Herd 1, and SCC and lactation were recorded once at the beginning of each month, the SCC and lactation results were repeated for the subsequent analyses.

As a reference, in terms of raw values, a healthy individual is characterised by a BCS within the range of 2 to 4 (AHDB Dairy, 2018) and a mobility score less than 1 (AHDB Dairy, 2013). In terms of milk production, a study conducted by Hanks and Kossaibaiti (2012), stated a target of 33kg/day milk yield and a SCC lower than 200,000 cells/ml represented a healthy individual. In a study conducted by Offer (2000) lameness increased after the 3rd lactation and King et al. (2017) found parities above 2 to be significantly associated with an increased chance of lameness.

2.2.3. Data analysis

To develop a multivariate analytical system that could take the herd data and combine the individual results, the software, MATLAB, was used to write a code that would be fit for purpose (Appendix 3).

The code worked by reading the Excel spreadsheet, taking each value and normalising it so the different units of data fell in the same range. As each variable changes differently in lame cows; for example, body condition score decreases, while mobility score increases; before the results were combined, the normalised values were organised into 4 subgroups. The values assigned reflected the scale used in the AHDB Mobility Score (2013), with 0 representing a healthy individual, and 3 representing a severely lame cow. To create the subgroups the normalised range for each herd was divided by 4; any values below the lowest quartile would be given a score of 0, while any values in the upper quartile were given a value of 3 – and vice versa for the inverse relationships of body condition score and milk yield. For example, any cows with a high SCC, when normalised, would fall into subgroup 4 and be assigned the value of 3. To reflect the opposite relationship of milk yield and lameness, any cows with low milk yields would fall into subgroup 1, and also be assigned the value 3, to represent its stronger link with lameness.

Once the values for each cow were categorised, their subgroup value was combined to give a ‘lameness score’. For example, if the raw data fell into subgroup 3 across all measures, the combined lameness score would be 15. This is an example of post-classification fusion, as the values were classified before they were combined (Jain *et al.*, 2005). As there were 5 variables used in this study, each with 4 subgroups with values from 0 to 3, the maximum lameness score was 15 and the minimum was 0. The lameness scores for the herd were displayed on a histogram, showing the distribution of scores within the group. The range of lameness scores varied depending on the herd being analysed as each analysis was specific to the group being tested.

To determine the lameness score for an individual cow, the user inputted that cow’s row number in Excel, where the code would then find the individual in the data set and present it separately as a line on the histogram. The lameness scores were presented in a table in Excel alongside the other variables for that cow.

2.2.4. Statistical analysis

2.2.4.1. Analysis of mobility score

As already mentioned, the AHDB Dairy Mobility Score (2013) was used by both farms included in this analysis. The mobility score is an ordinal scale from 0 to 3; 0 representing a healthy gait, to 3 representing severely lame individuals (see Table 1). In this study, mobility scores were left in their raw form for the correlation and regression analysis. However, to generate a receiver operating characteristics (ROC) curve, to find the area under the curve (AUC), the mobility scores were transformed into dichotomous values, lame and non-lame. Lame cows, those with a mobility score of 2 or 3, were given a value of 2. Non-lame cows, those with a mobility score of 0 or 1, were given a value of 1. This method was taken from Van Hertem et al. (2016) and allowed us to determine if the lameness score could identify a lame individual with the same accuracy as the mobility score.

The frequency of lame cows vs. non-lame cows, based on the mobility score, was presented in separate bar charts for each herd.

2.2.4.2. Analysis of lameness score

To analyse the results statistically, SPSS software was used. Descriptive statistics for each month of data were calculated to show the number of cows involved in the analysis and the range of data included in the score.

Bivariable correlation analysis was used to determine the strength and direction of the relationship between two individual variables (McCormick, 2015). This method enabled us to determine the strength of relationship between the predictor variables; milk yield, SCC, lactation/parity, mobility score and BCS, and our lameness score. Pearson correlation coefficients were calculated for each relationship and presented in a table.

Linear regression took the relationship between each of the variables one step further as it tried to predict the lameness score based on the inputted variables. Linear regression seeks to predict a dependent variable from one or more independent variables (McCormick, 2015). In this study, linear regression was used to determine if lameness score (the dependent variable) could be predicted from milk yield, SCC, lactation/parity, BCS and mobility score. As we used multiple independent variables, the form of linear regression used was a multiple regression (McCormick, 2015).

In multiple regression, the correlation between the dependent variable and the independent variables is represented as R. The closer R is to 1 the stronger the relationship (McCormick, 2015). The proportion of variance of the dependent variable that can be predicted from the independent variables is represented by R Square (McCormick, 2015). A strong relationship would give an R value of >0.7 and an R Square >49%-50% (McCormick, 2015).

2.2.5. Validation of method

In order to test the ability of our model at predicting lameness we used a ROC curve to measure the sensitivity of the model – its ability to detect lame cases – and the specificity of the model – its ability to detect non-lame cows (Van Hertem *et al.*, 2016). As the mobility score is a widely used method it was the classifier we used to perform our comparisons. To measure the performance of our classifier, we calculated the AUC, a portion of the area of the unit square (Van Hertem *et al.*, 2016; Bradley, 1997). This value always falls between 0 and 1.0, with an area of 1 representing a perfect diagnostic test (Van Hertem *et al.*, 2016). The success of a diagnostic test based on its AUC can be broken down into the following categories: fail (AUC= 0.5 to 0.6), poor (0.6 to 0.7), fair (0.7 to 0.8), good (0.8 to 0.9) and excellent (0.9 to 1.0) (Van Hertem *et al.*, 2016; Bradley, 1997).

To further validate the performance of our classifier, to statistically test the significance of any differences in the AUC measures and accuracy, Analysis of Variance (ANOVA) was used (Bradley, 1997).

2.3. Results

Before the code was run, the cows that did not have data for all five predictor variables had to be removed from the study. Due to the often-sporadic nature of data collection on farm, a different number of cows had to be removed from the analysis for each time point. The total number of cows in each herd, and the total number of cows used in the analysis are reported in the tables below.

Table 2: The total number of cows included in this study, from Herd 1. The table below states the number, and percentage, of cows from Herd 1, which had data for each of the five variables, milk yield, lactation, SCC, BCS and mobility score, required for the analysis at each time point. Cows which did not have data for each of the variables were removed from the analysis.

Herd 1	Number of cows analysed	Percentage of herd used
08.01.18	366	76.3%
22.01.18	343	71.5%
05.02.18	430	89.6%
19.02.18	371	77.3%
05.03.18	449	93.5%
19.03.18	366	76.3%
Herd Total	**480**	

Table 3: The total number of cows included in this study, from Herd 2. The table below states the number and percentage of cows from Herd 2 that had data for each of the five variables required for the analysis. Cows which did not have data for each of the variables were removed from the analysis.

Herd 2	Number of cows analysed	Percentage of herd used
March 2016	31	15.5%
August 2016	38	19.0%
September 2016	38	19.0%
November 2016	41	20.5%
January 2017	79	39.5%
July 2017	49	24.5%
Herd Total	**200**	

While the data collection for Herd 1 was not consistent, with a different number of cows being removed from each month, it was less sporadic than Herd 2. The months had to be selected based on the size of raw data, as many months did not have enough raw data to be analysed. However, even though the largest data sets were chosen, a lot of the cows still had to be removed because of missing values. It is likely the small sample size later influenced the data analysis, and it is for this reason that the herd results will be discussed separately.

2.3.1. Herd 1

2.3.1.1. Lameness prevalence

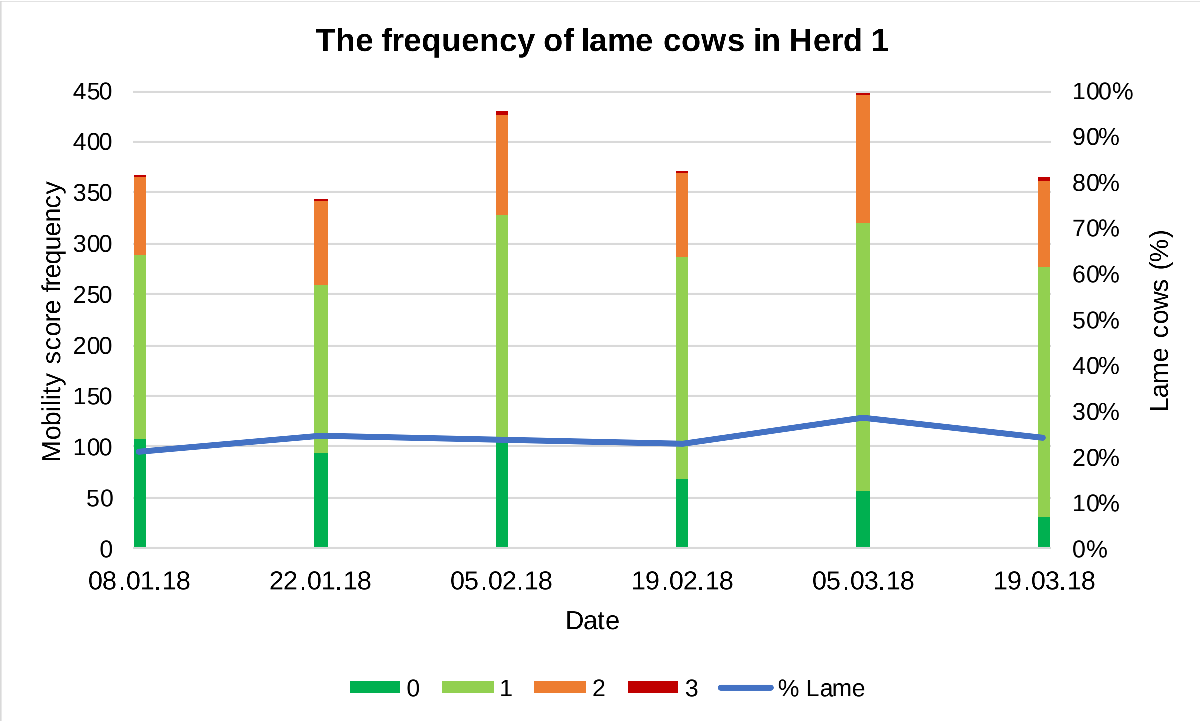

Figure 2: A graph to show the frequency of mobility scores and the percentage of lame cows within Herd 1. This figure shows the percentage of lame cows within Herd 1, and the frequency of mobility scores, recorded at each time point.

As illustrated in Fig. 2, the majority of cows in Herd 1 were non-lame individuals, scoring 1 or below. The mean prevalence of lameness was 24.2%, below the estimated UK average of 28.2% (Griffiths *et al.*, 2018). This graph shows the spread of raw mobility scores, recorded on farm, within the herd against the average lameness prevalence, across the five time points. There were only a few score 3 cows, showing this herd's general health in regard to lameness prevalence.

2.3.1.2 Analysis of lameness score

The mean lameness score and the raw mobility score have been presented in the figures below. To view the descriptive statistics for each time point, and each variable, refer to Appendix 4.

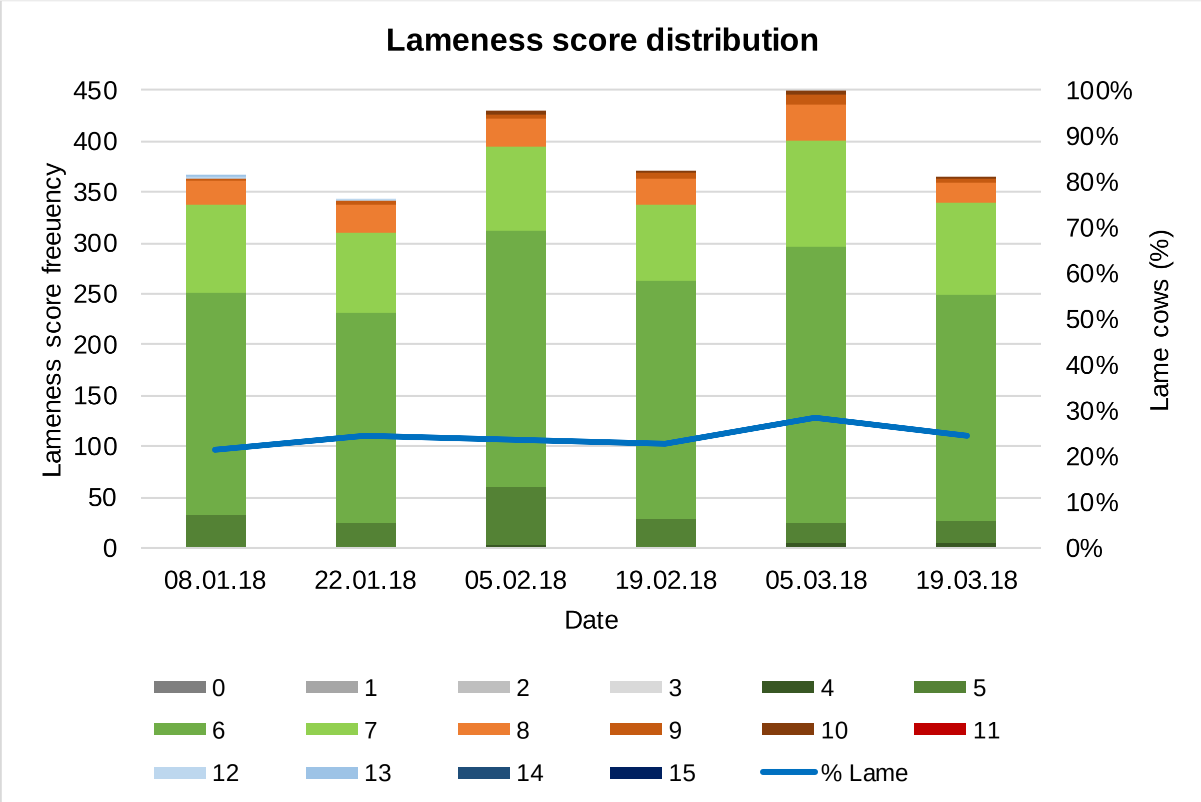

Figure 3: The frequency of lameness scores and the percentage of lame cows within Herd 1. This figure shows the percentage of lame cows within Herd 1, and the different lameness scores recorded at each time point. The columns represent the spread of lameness scores across the herd, as calculated by the multivariate analytical system developed in this project. The percentage of lame cows was calculated from the raw mobility scores, as recorded on farm. The mean lameness score across the time points was 6.

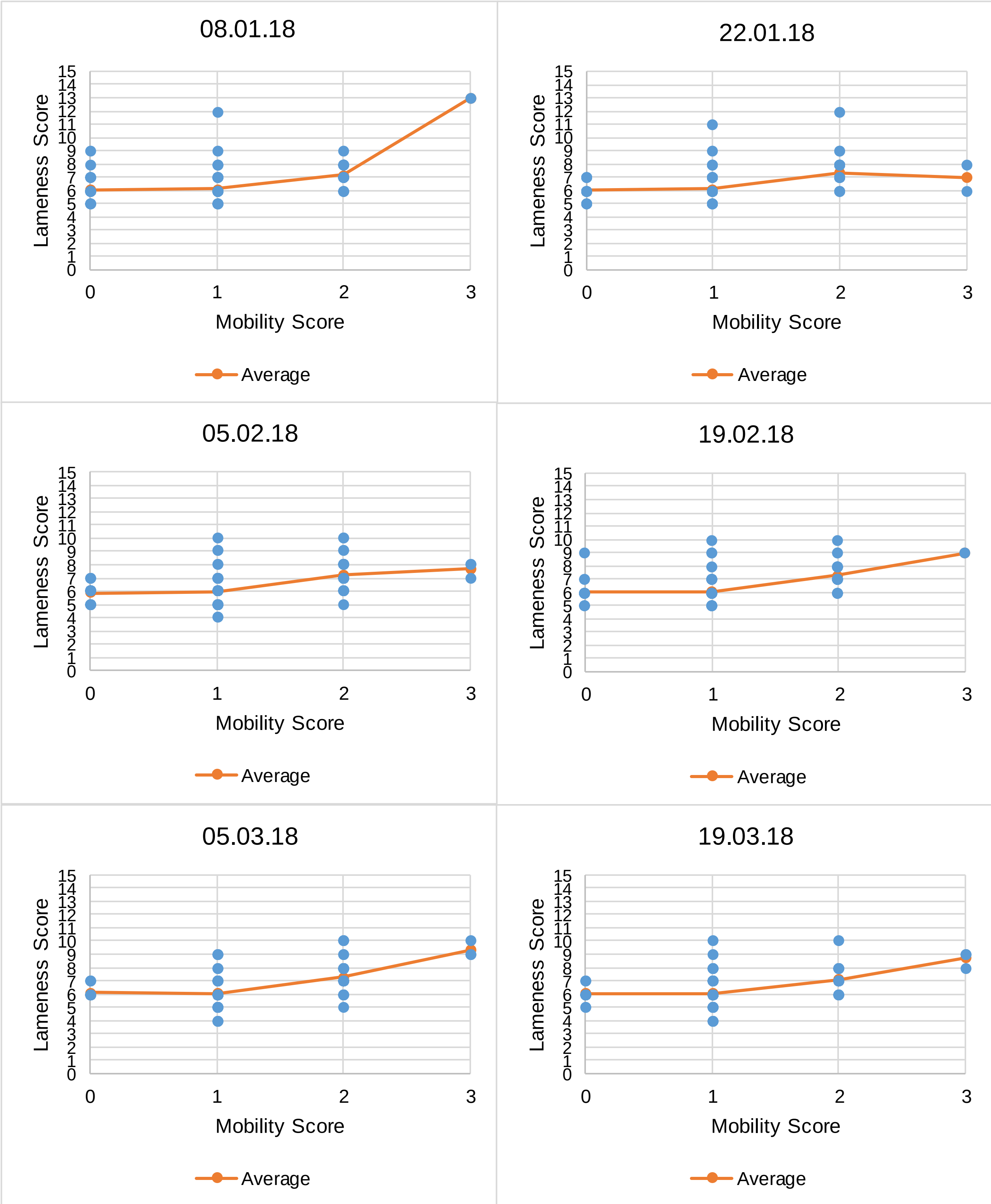

Figure 4: A figure to show the relationship between lameness score and mobility score. This figure shows the range of mobility scores and corresponding lameness scores, as shown by the blue markers. The mean lameness score for each mobility score is shown as an orange line.

As can be seen in the figures above, the time point 05.03.18 had the highest prevalence of lameness and the highest average lameness score. However, if the lameness scores were rounded to the nearest whole number, all of the time points showed the same average lameness score of 6 and mobility score of 1. This shows that Herd 1 had relatively consistent levels of lameness across the 3-month period.

While Fig. 4 does not show the frequency of cows that represent each blue dot, it does show the large spread of lameness scores for mobility scores 1 and 2, highlighting how mobility score 1 cows could be presenting other signs that may be missed on the mobility score. The lameness and mobility scores seem to similarly identify score 3 cows as this score shows a smaller range.

2.3.1.2.1. Bivariable correlation analysis

In order to evaluate the separate links between each variable and the lameness score, bivariable correlation analysis was conducted. The results for each month have been presented below, to see the variation with time.

Table 4: Results of the bivariable correlation analysis for Herd 1. The table below shows the strength of individual correlations (R) between each of the recorded variables and the lameness score. Significant positive correlations can be seen between lameness score and mobility score, at the 0.01 level, for all time points. Significant positive correlations can also be seen between lameness score and the other predictor variables. As expected negative correlations were reported, at the 0.01 level, for BCS and lameness score for all time points. Negative correlations, at the 0.05 level, were reported between milk yield and lameness score for 08.01.18 and 05.02.18, but no correlations were found for the other time points.

	Variable					
Date	Milk Yield	SCC	Lactation	BCS	Mobility	Lameness
08.01.18	-.122*	.533**	.601**	-.178**	.472**	1
22.01.18	-.094	.490**	.634**	-.186**	.538**	1
05.02.18	-.124*	.322**	.524**	-.304**	.542**	1
19.02.18	-.098	.311**	.628**	-.215**	.539**	1
05.03.18	-.055	.359**	.634**	-.217**	.588**	1
19.03.18	-.055	.359**	.634**	-.217**	.588**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

As expected, BCS and milk yield were negatively associated with lameness score. As lameness score increased BCS and milk yield decreased. What was not anticipated was the weak correlation found between lameness score and milk yield. To investigate these results, further analysis was conducted and will be discussed in Section 2.3.3.1.

2.3.1.2.2. Multiple regression analysis

Multiple regression analysis was conducted to establish whether the lameness score could be predicted by the indicator variables: milk yield, SCC, lactation, BCS and mobility score. The strength of the variables combined predictive ability is represented in the R value.

Table 5: A summary table to show the results from the multiple regression analysis for Herd 1. As can be seen in the table below, for each time point high R values were reported for the lameness score. This means that the lameness score could be predicted by the indicator variables BCS, mobility score, lactation, SCC and milk yield.

<u>Summary of multiple regression</u>

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
R	.808[a]	.811[a]	.780[a]	.793[a]	.828[a]	.768[a]
R Square	.653	.658	.608	.629	.685	.618
ANOVA Regression Sig.	<0.001[a]	<0.001[a]	<0.001[a]	<0.001[a]	<0.001[a]	<0.001[a]

a. Predictors: (Constant), Mobility, BCS, SCC, Milk Yield, Lactation

Each of the time points have an R value greater than 0.7 and an R Square over 49-50%, showing a strong correlation between the lameness score and the predictor variables, milk yield, lactation, SCC, mobility and BCS.

2.3.1.3. Data validation

Table 6: A summary table to show the results from the AUC analysis for Herd 1. As shown in the table below the AUC results for Herd 1 were positive, with 5 out of the 6 time points reporting excellent AUC values.

Summary of AUC results

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
Area	.890	.911	.905	.910	.921	.907
Std. Error[a]	.021	.019	.019	.019	.016	.018

a. Under the nonparametric assumption

The proposed classifier, the lameness score, has an average AUC value of .907, showing excellent performance. These results show that the proposed scoring method is able to successfully detect lame cases, as identified by the mobility score.

2.3.2. Herd 2

As, on average, only 23% of Herd 2 could be used in the analysis, the results were influenced by the small sample sizes. However, as they highlight an important weakness of the proposed method, which will be discussed further, the summary results are given below.

2.3.2.1. Lameness prevalence

Due to the sample size used in the analysis of Herd 2 it is difficult to get a holistic view of the health of the herd as a whole. Looking at lameness prevalence within the sample, depending on the month chosen, the herd could be identified as being above the national lameness average of 28.2% (Griffiths *et al.*, 2018), simply due to the selection of cows chosen. It is difficult to make reliable conclusions by only looking at an average 23% of the herd. Therefore, when looking at the percentage of lame cows, displayed in Fig. 5 and Fig. 6, it is important to remember the sample size before making judgements about lameness prevalence.

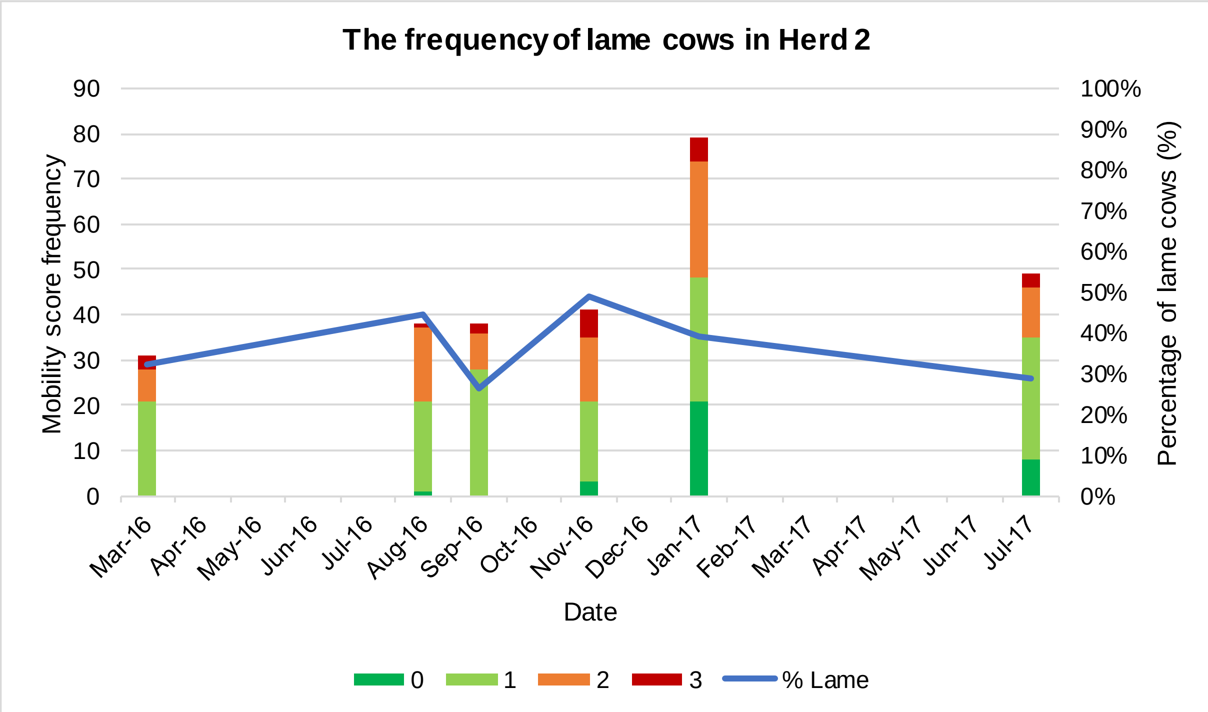

Figure 5: The frequency of mobility scores and the percentage of lame cows within Herd 2. This figure shows the percentage of lame cows within Herd 2, and the different mobility scores recorded at each time point.

2.3.2.2 Analysis of lameness score

Despite the high average prevalence (36.7%) of cows scoring either 2 or 3 on the mobility score, the mean lameness score was 6. Without further analyses it is difficult to determine the parameters of what is lame using the lameness score, therefore it is difficult to conclude whether the two scores are reporting different things.

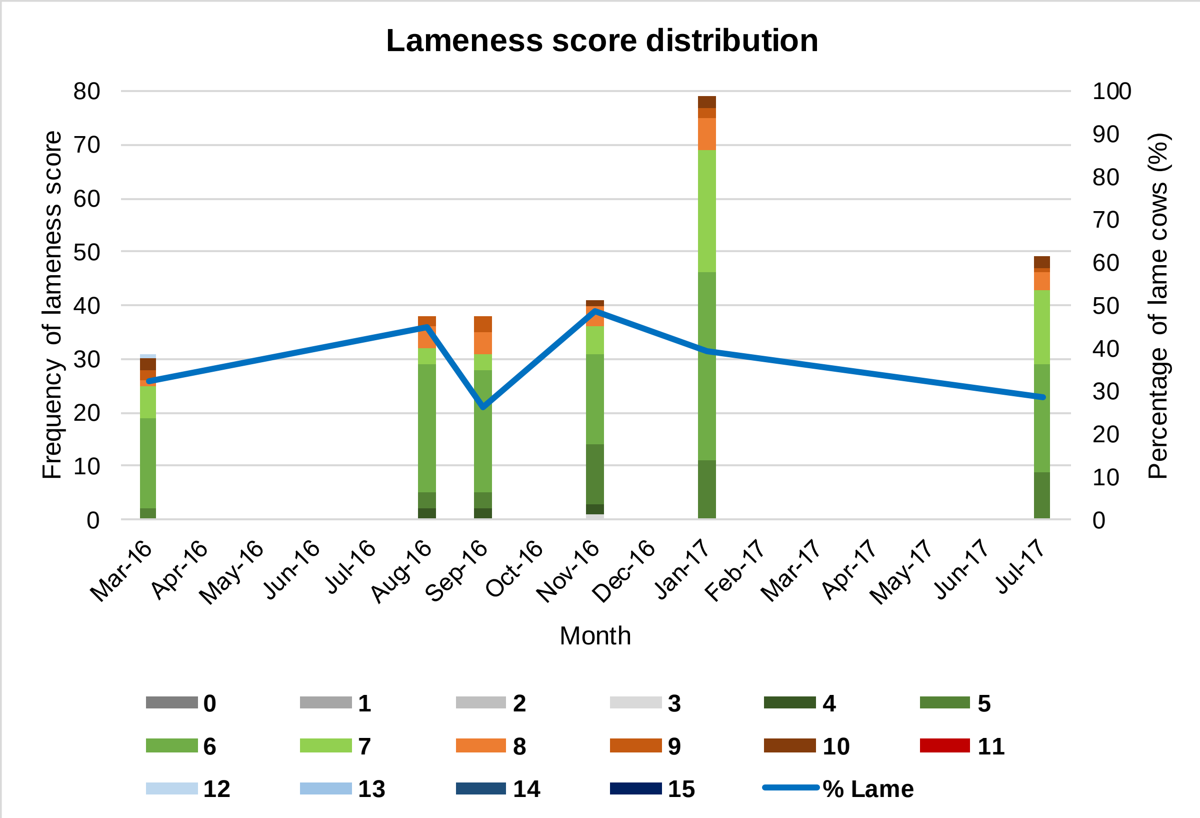

Figure 6: A graph to show the frequency of lameness scores within Herd 2 and the percentage of lame cows. This figure shows the distribution of lameness scores within Herd 2, alongside the percentage of lame cows, determined by those cows that scored a 2 or 3 using the mobility score. The mean lameness score across the 6 months included in the analysis was 6 out of 15.

For full descriptive statistics for each time point, refer to Appendix 5.

2.3.2.2.1. Bivariable correlation analysis

The tables below show the independent correlations found between each time point and variable. These tables show the strength of the relationship between the chosen predictor variables and the lameness score. In the instance of Herd 2, the direction of the correlations shows the limitations of the small data set.

Table 7: Results of the bivariable correlation analysis for Herd 2. As illustrated in the table below, there were significant positive correlations, reported at the 0.01 level, between the lameness score and the mobility score for March 2016, September 2016, January 207 and July 2017. There were also significant correlations found between lameness score and SCC, parity and BCS. However, there were no reported correlations reported between milk yield and lameness score.

			Variable			
Month	Milk Yield	SCC	Parity	BCS	Mobility	Lameness
March 2016	-.036	.487**	.745**	-.377*	.719**	1
August 2016	-.072	.156	-.226	.079	-.263	1
September 2016	-.125	.372*	.483**	.331*	.667**	1
November 2016	-.081	.454**	.523**	-.481**	.364*	1
January 2017	-.079	.371**	.389**	-.301**	.630**	1
July 2017	-.187	.714**	.755**	-.212	.408**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

When analysing Herd 2 it is evident that weaker correlations were found between the variables and mobility score, and the variables and lameness score. If these correlations are compared with Herd 1, it is more evident that it is an issue with the size of the sample used, rather than the performance of the scoring system.

2.3.2.2.2. Multiple regression analysis

Table 8: A summary table of the multiple regression analysis for each month for Herd 2. As shown in the table below August 2016 had a very poor R result, highlighting for that particular month, the lameness score was unable to be predicted by mobility score, BCS, SCC, milk yield and parity. March 2016 had the most positive results with a strong R value of .930. All time points showed significant values, apart from August 2016.

Summary of multiple regression

	Mar 2016	Aug 2016	Sep 2016	Nov 2016	Jan 2017	Jul 2017
R	.930[a]	.384[a]	.845[a]	.802[a]	.779[a]	.914[a]
R Square	.865	.147	.714	.642	.607	.835
ANOVA Regression Sig.	<.001[a]	.377[a]	<.001[a]	<.001[a]	<.001[a]	<.001[a]

a. Predictors: (Constant), Mobility, BCS, SCC, Milk Yield, Parity

In general, excluding August 2016, Herd 2 showed positive regression results. Therefore, based on the analysis, the lameness score can be predicted by the associated variables: mobility score, BCS, SCC, milk yield and parity. This is to be expected, as the mobility score formed part of the lameness score.

2.3.2.3. Data validation

Table 9: A summary table of the AUC analysis for each month. As shown in the table below the AUC results for Herd 2 were varied, with only 1 month, January 2017, reporting an excellent AUC value. August 2016 had the lowest AUC value of .360, which would be classed as a failed result.

Summary of AUC results

	Mar 2016	Aug 2016	Sep 2016	Nov 2016	Jan 2017	Jul 2017
Area	.848	.360	.870	.627	.915	.788
Std. Error[a]	.081	.089	.070	.089	.034	.067

a. Under the nonparametric assumption

The inconsistent R values, and lower AUC results for Herd 2 are likely due to the small sample size influencing the data. The consistent results for Herd 1, with a mean AUC result of .907, adds weight to the likelihood that Herd 2 results illustrate the importance of routine data collection across the whole herd rather than an error in the method. This likelihood is further supported by the largest sample size from this analysis, January 2017, showing the only positive AUC result. The limitations of the dataset used for Herd 2 render it inadequate to accurately evaluate the capability of the lameness score.

2.3.3. Analysis of the lameness score without milk yield

As milk yield often correlated weakly, or not at all, to lameness score it was necessary to evaluate the performance of the lameness score with milk yield removed (see Appendix 4 for amended MATLAB script). Due to the limitations associated with Herd 2's sample size the analysis was only performed using Herd 1. The key measures of performance; correlation, regression and area under the curve, are shown below.

2.3.3.1. Bivariable correlation analysis

Table 10: A table to show the results of the bivariable correlation analysis for Herd 1, with milk yield removed. As shown in the table below, there were significant correlations, at the 0.01 level, between the lameness score and the four other variables; lactation, SCC, BCS and mobility. As expected the correlation between lameness and BCS was negative, as BCS decreases lameness score increases.

	Variable				
Date	SCC	Lactation	BCS	Mobility	Lameness
08.01.18	.551**	.683**	-.224**	.490**	1
22.01.18	.521**	.699**	-.230**	.547**	1
05.02.18	.326**	.621**	-.367**	.557**	1
19.02.18	.319**	.705**	-.274**	.550**	1
05.03.18	.371**	.681 **	-.246**	.598**	1
19.03.18	.354**	.583**	-.283**	.570**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Unlike the original bivariate correlation analysis (see Section 2.3.1.2.1.), significant correlations, all at the 0.01 level, were reported between all variables. By removing milk yield, the weak correlation was removed, suggesting a more representative lameness score. Before that conclusion is made, further analysis is necessary.

2.3.3.2. Multiple regression analysis

Table 11: A summary table of the multiple regression analysis for each month for Herd 1, with milk yield removed from the scoring system. As shown in the table below, all months had strong R values, suggesting the lameness score could be predicted by mobility score, BCS, SCC and lactation.

Summary of multiple regression

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
R	.859[a]	.862[a]	.823[a]	.843[a]	.857[a]	.822[a]
R Square	.738	.744	.678	.711	.735	.675
ANOVA Regression Sig.	<.001[a]	<.001[a]	<.001[a]	<.001[a]	<.001[a]	<.001[a]

a. Predictors: (Constant), Mobility, BCS, SCC, Lactation

The average R value from the original multiple regression analysis (see Section 2.3.1.2.2.) was 0.804. The average R value for this analysis, with milk yield removed from the scoring system, is 0.844. Therefore, the R value improved by 5.02% when milk yield was not included in the lameness score, suggesting the lameness score is better predicted without its inclusion.

2.3.3.3. Data validation

Table 12: A summary table of the AUC analysis for Herd 1, with milk yield removed. 3 months reported excellent AUC results (>.9) with 2 months showing good results (>0.8). These results suggest that the lameness score can predict the lame individuals classified by the mobility score.

Summary of AUC results

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
Area	.899	.912	.893	.904	.926	.903
Std. Error[a]	.018	.018	.021	.020	.014	.018

a. Under the nonparametric assumption

The average AUC value for the original analysis (see Section 2.3.1.3.) was 0.9074. The average AUC result for Herd 1, with milk yield removed, is 0.9062, a difference of 0.0012. The average standard error, under the nonparametric assumption, was 0.0188 for the original analysis and 0.0182 with milk yield removed. The difference between the analyses is too narrow to suggest one as more successful. However, as they both show positive AUC results across the months tested, the lameness score is still able to identify lame individuals.

2.3.4. Analysis of the lameness score without the mobility score

The results already discussed show how the lameness score has the potential to expand the capability of the mobility score. However, as mobility score is used in the lameness score, a limitation of the method was that time-consuming data collection was still required to mobility score the cows. Ideally the lameness score should work independently of the mobility score, circumventing its use and reducing the amount of data collection needed by the farmer or vet. To test this capability, mobility scores were removed from the scoring system and new lameness scores were generated (see Appendix 5 for the amended

MATLAB script). Due to the limitations of the data from Herd 2, the analysis was only conducted for Herd 1.

2.3.4.1. Bivariable correlation analysis

Table 13: A table to show the results of the bivariable correlation analysis for Herd 1, with mobility score removed. As shown in the table below, there were significant correlations, at the 0.01 level, between the lameness score, lactation and SCC. Significant, negative correlations between lameness and BCS were found, at the 0.01 level; an expected result as BCS decreases lameness score increases. No correlations were reported between lameness score and milk yield.

	Variable				
Date	Milk Yield	Lactation	SCC	BCS	Lameness
08.01.18	-.081	.604**	.593**	-.240**	1
22.01.18	-.010	.622**	.578**	-.232**	1
05.02.18	-.051	.485**	.364**	-.366**	1
19.02.18	-.052	.580**	.397**	-.287**	1
05.03.18	.024	.635**	.400**	-.253**	1
19.03.18	-.055	.510**	.468**	-.287**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

When mobility score was removed from the analysis, the results mirror those from the original bivariate correlation analysis (see Section 2.3.1.2.1.), as lactation, SCC and BCS all shared significant correlations with the lameness score; while milk yield showed no relationship. The inclusion of milk yield, and its link to lameness, is something that will be discussed further.

2.3.4.2. Multiple regression analysis

Table 14: A summary table of the multiple regression analysis for each month for Herd 1, with mobility score removed from the scoring system.
As shown in the table below, all months had strong R values, suggesting the lameness score could be predicted by milk yield, BCS, SCC and lactation.

Summary of multiple regression

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
R	.787[a]	.772[a]	.715[a]	.739[a]	.765[a]	.712[a]
R Square	.619	.595	.511	.546	.585	.507
ANOVA Regression Sig.	<.001[a]	<.001[a]	<.001[a]	<.001[a]	<.001[a]	<.001[a]

a. Predictors: (Constant), BCS, SCC, Milk Yield, Lactation

The average R value from the multiple regression analysis for Herd 1, with mobility score removed, is 0.755. This is a 6.0% decrease compared with the average R value, 0.804, from the original multiple regression analysis (see Section 2.3.1.2.2.). While the R values are greater than 0.7, suggesting each of the time points show a strong correlation between the lameness score and the predictor variables, the R values are weaker when mobility score is removed.

2.3.4.3. Data validation

Table 15: A summary table of the AUC analysis for Herd 1, with mobility score removed. With the mobility score removed the lameness score failed 5 out of 6 months (AUC = 0.5 to 0.6), with 05.03.18 showing a poor result (AUC = 0.6 to 0.7). The table below shows that without the mobility score included, the lameness score is unable to identify lame individuals as previously classified by the mobility score.

Summary of AUC results

	08.01.18	22.01.18	05.02.18	19.02.18	05.03.18	19.03.18
Area	.555	.588	.598	.596	.605	.541
Std. Error[a]	.038	.037	.034	.038	.031	.035

a. Under the nonparametric assumption

The average AUC result, with mobility score removed, is 0.581. This is a 36% decrease from the original analysis' AUC value of 0.907 (see Section 2.3.1.3.). The lameness score fails to identify lame individuals when the mobility score is removed. This raises the question of whether the lameness score generated good AUC results in the original analysis because the mobility score was used both in the score and as the state variable for the ROC curve. The limitations of the lameness score in expanding the mobility score will be discussed in Section 4.1.1.

3. Expert consultation on lameness detection and chronic lameness

3.1 Introduction

The reality of the shift to intensive production is that farmers have limited time and money to thoroughly observe their herds (Leach *et al.*, 2010a; Leach *et al.*, 2010b). Research found 90% of farmers consider lameness to be a lesser concern than other welfare issues, with 62% believing it to not be a top priority (Leach *et al.*, 2010a). These statistics are corroborated by the general finding that lameness prevalence is around 3 times greater than the estimates given by farm employees (Espejo *et al.*, 2006; Whay *et al.*, 2003; Cutler *et al.*, 2017). This has led to previous studies (Main *et al.*, 2012; Leach *et al.*, 2010a; Leach *et al.*, 2010b), focusing on the farmers; what they think about lameness, and how changing their husbandry practices could make a positive difference, for both them and the cows. The results of these studies found that farmers do take pride in their herds and wish to avoid their livestock experiencing pain and suffering (Leach *et al.*, 2010b; Kristensen and Enevoldsen, 2008; Valeeva *et al.*, 2007; Von Keyserlingk *et al.*, 2009). The issue of lameness prevalence extends beyond the farmer, with other factors taking a role.

Alongside farmers, vets and researchers can provide important value to livestock management with their specialist knowledge of animal husbandry. Therefore, it is necessary to consult these individuals in order to get an accurate understanding of lameness. Consultations are a useful way to gain an understanding of where gaps in the research lie. The importance of first understanding current barriers before implementing change, has been shown in the research conducted by Leach et al. (Leach *et al.*, 2010a; Leach *et al.*, 2010b); in this study, face-to-face interviews were conducted with farmers to better understand the barriers they perceived to inhibit how they deal with lameness, and what motivated them to make a change. By using interviews, the study was able to postulate what prevented farmers from taking action and provided more targeted information as to how these barriers could be overcome (Leach *et al.*, 2010a).

Interviews provide a first-hand account from the people who see, and deal with, lame cows on a regular basis. In this study, interviews were used to understand the most relevant variables to measure when diagnosing lameness. The experts were given an opportunity to articulate what traits they would record, if they weren't bound by what is required by the industry, and policy makers. This provided more depth to the proposed multivariate analytical system and will allow us to tailor its future implementation for maximum success. The use of interviews also enabled us to identify how experts define lameness, and what they consider to be the most important changes displayed in a lame individual.

3.2. Materials and methods

The full consultation process was planned before the interviews were conducted. By identifying limiting factors, such as the time required to collect and analyse the data, and the availability of participants, any difficulties were pre-empted and catered for (Bengtsson, 2016). As part of the planning process, this project considered five factors as suggested by Bengtsson (2016), before data was gathered:

1. The aim- what is the purpose of the interview? What are we trying to find out that hasn't already been explored?
2. The sample and unit of analysis- what is the sample size needed to gain an accurate depiction of lameness in UK dairy farms?
3. The choice of data collection method- what is the required depth of analysis?
4. The choice of analysis method- how will the verbal responses be processed into informative data?
5. Practical implications- what are the ethical implications of the study? Have the participants been given the full information regarding the purpose of the study and their rights to confidentiality and the ability to withdraw at any point?

These five factors have been applied to this research project and are discussed in more detail below.

3.2.1. The aim

There were two main aims of this study: firstly, to determine the variables experts would measure to identify lameness, were they not bound by pre-existing data and requirements; and secondly, to get a greater understanding of the how the issue of chronic lameness is defined, and other associated barriers to progress in the industry.

3.2.2. Sample size and unit of analysis

Experts either had a farm veterinary background or had been involved in the study of lameness prior to this research project. Ethical approval from the University of Bristol's Health Sciences Faculty Research Ethics Committee (FREC) was obtained before the participants were approached and consent forms were sent out to confirm their desire to participate. Ten experts were approached in total, eight used for the actual study (four of whom were qualified veterinarians, two of whom were in academia but as qualified veterinarians, and two who were academics) and two used for a pilot study (both were qualified veterinarians) to identify any preliminary issues with the interview method. The unit of analysis refers to the sample chosen and whether the group is to be analysed together or as separate entities (Bengtsson, 2016). In this study it was unnecessary to split the sample into subgroups as; the sample size was too small, and no external factors, such as gender, were considered to be confounding variables in the way the participants responded.

Due to the limited available time that the experts had to offer, the interviews were designed to be short in duration, to encourage more participants to take part. The consultations were not conducted to get an in-depth analysis but a brief summary of the issue of lameness as it is today.

3.2.3. Data collection

The interviews were semi-structured, a method chosen for its use of an interview guide and ability to explore certain topics in depth, depending on the responses given by the interviewees (Galletta, 2013; Bernard, 2006). Participants were not restricted in the number of answers they could give to each question. Three core questions were asked in each interview:

1. From your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?
2. If you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? For example, would you follow the current procedure of mobility scoring them, or would you include other indicators?
3. Finally, could you give me your definition of chronic lameness?

Then dependent on the participants' time further questions were asked. By allowing participants to lead parts of the interview, more authentic responses could be gained as the participant had the ability to delve into their own experiences (Galletta *et al.*, 2013).

Before the data were collected, two pilot interviews were conducted to ensure the questions met the aim of the consultation and that there were no leading questions that may influence the participants' responses (Witschey *et al.*, 2013). As only two pilot interviews were performed, the questions were changed if either participant did not understand the context of the question. This made it an iterative process, with the questions altered where appropriate. Mirroring the study conducted by Leach et al. (Leach *et al.*, 2010a), the results of the pilot study were used to refine and improve the consultation process. If useful information was yielded from a spontaneous question it was added to the script for future interviews (Witschey *et al.*, 2013). This added a process of refinement to the interview process, to further ensure the aims of the project were met.

My colleague and I went through the interview questions prior to the consultation to ensure consistent delivery and collection of results (Leach *et al.*, 2010a). During the interview, participants were recorded using a voice recorder. The responses were then transcribed into written form where they were analysed using NVivo (v. 10, QSR International). The participants consented to being recorded before the consultation began and were given the option on the consent form to withdraw from the study at any time.

3.2.4. Data analysis

To analyse the data, content analysis was used to explore the written text and allow it to be analysed both qualitatively and quantitatively (Pope *et al.*, 2000). Content analysis is a way of providing a view of the entire sample of interviews through a process of condensation and categorisation (Leavy and Prior, 2014).

The data analysis process follows a 4-stage structure described by Bengtsson (2016), given below:

1. Decontextualisation
2. Recontextualisation
3. Categorisation
4. Compilation

The stages were repeated to ensure the reliability of the analysis (Bengtsson, 2016; Mazaheri *et al.*, 2013).

The process of decontextualisation required familiarisation with the data. It was necessary to recognise the themes running through the text to get an idea of how to break the responses down into meaning units (Bengtsson, 2016; Graneheim and Lundman, 2004). For this study the themes included: changes displayed in a lame cow, interesting variables to consider when identifying chronic lameness and definitions of chronicity. Nodes were created on NVivo for each theme. Recontextualisation is a stage designed to make sure all aspects of the content have been covered and relate to the aim of the study (Burnard, 1991).

When the themes were identified, the responses were categorised into meaning units (Graneheim and Lundman, 2004). Relevant information was highlighted and coded into the appropriate node. When the participants' responses were coded, the contents of each node presented the key words from each interview.

The final stage, compilation, is the way in which the categories and themes are presented. In order to present the information diagrammatically, the key words were interpreted and further grouped based on similarity, for example "lack of weight bearing" included "reduced mobility" and "limping". This process ensured synonyms weren't presented separately. The frequency of each key response was counted and presented as a pie chart using, Excel.

3.2.5. Practical implications

Before the interview began the participants were sent an information sheet (Appendix 8) giving them the full details of the study; its aims and objectives, what was hoped to be gained from the interaction and a topic guide (Appendix 9). They were also sent a consent form (Appendix 10), which informed them that their responses would be kept anonymous and that they had the ability to withdraw from the study at any point they wished. Once they had signed and returned the consent form the interview began.

3.3. Results

3.3.1. Pilot studies

Following the two pilot interviews, changes were made to the questions (Appendix 11) to ensure the aim of the study was met in subsequent interviews. The changes that were made to the core questions can be found in Appendix 12.

3.3.2. Interviews

As three questions were asked in every interview the recurring themes will be discussed separately below. The main themes are: the changes displayed by a lame cow, identifiers of a chronically lame individual, and the experts' definition of chronic lameness. An additional theme of the pros and cons of the mobility score will also be discussed as this was a question posed to the majority of participants. The participants' interview transcripts can be found in Appendix 13.

3.3.2.1. Most important changes displayed in a lame cow

The first question asked the participants to give the most important changes displayed by a lame cow. The changes given have been further divided into physical, behavioural and productivity changes.

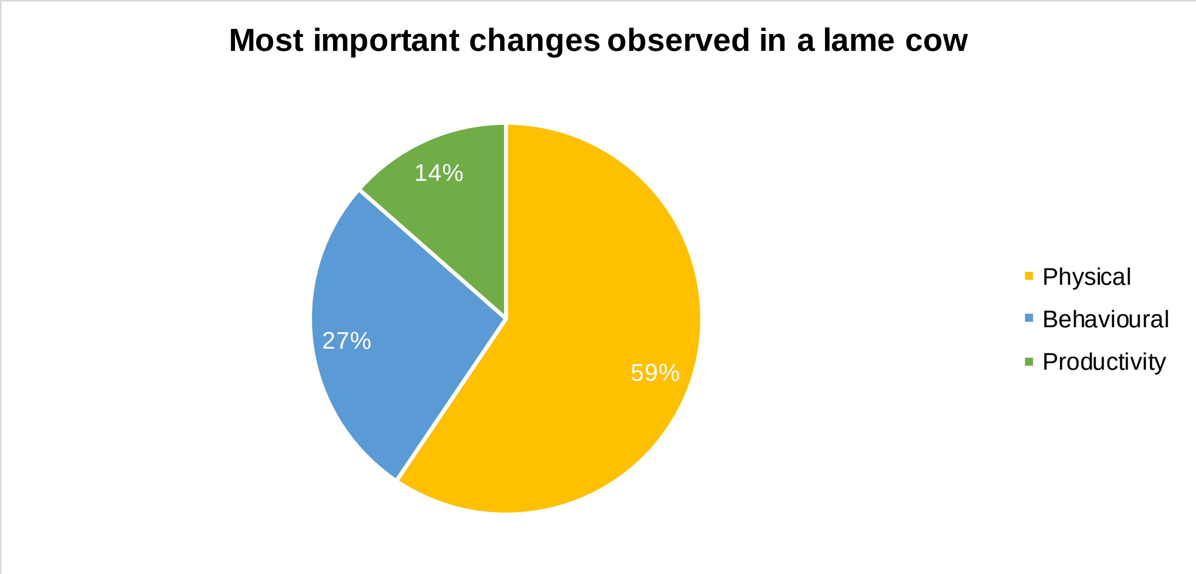

Figure 7: A pie chart to show the total number of responses that fall into to each category: physical, behavioural and productivity changes observed in a lame cow. This figure shows the categorisation of important changes observed by experts. Of the 37 responses, physical changes were the most commonly mentioned (accounting for 59% of answers given), with changes in productivity the least mentioned (accounting for 14% of answers given).

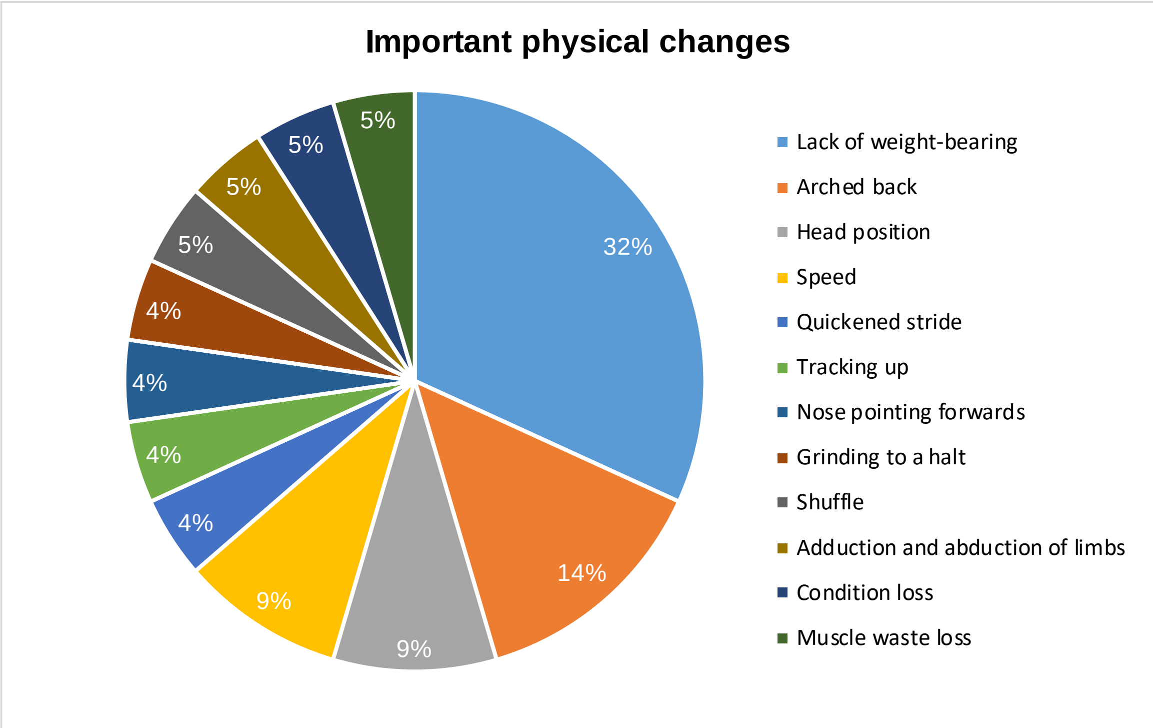

Figure 8: A pie chart to show the physical changes mentioned by the experts. This figure shows the different physical changes experts look for when identifying a lame cow. Of the 22 physical changes listed, lack of weight-bearing was the most common answer among experts (7 responses), followed by the posture of the cow (total of 5 responses), and the speed at which it walks (total of 3 responses).

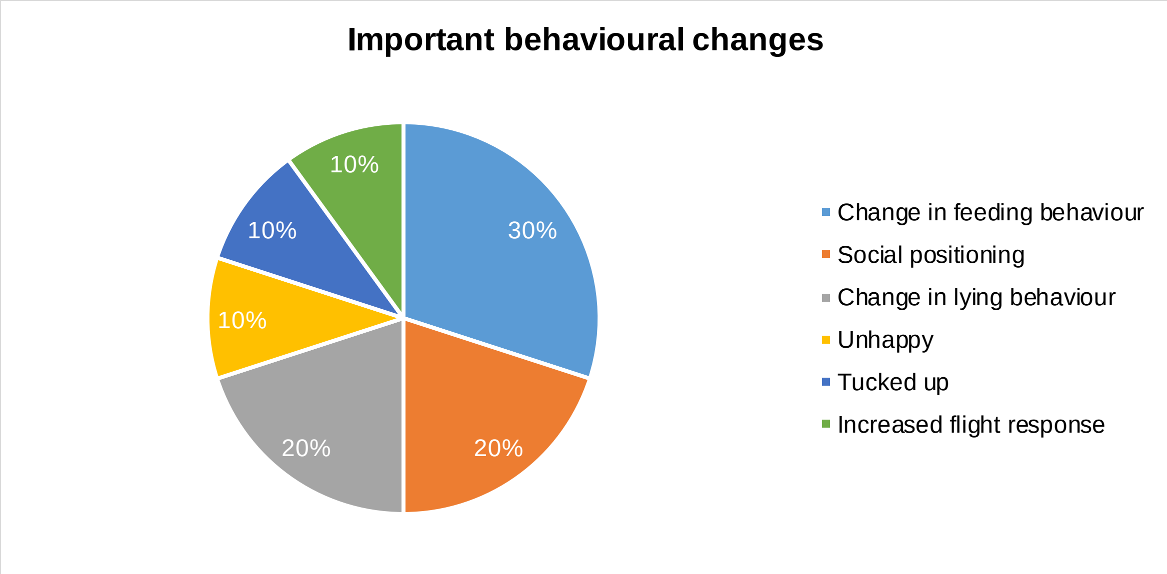

Figure 9: A pie chart to show the behavioural changes mentioned by the experts. This figure shows the important behavioural changes experts look for when identifying a lame cow. Of the 10 behavioural changes mentioned, a change in feeding behaviour was the most common identifier, followed by a change in lying behaviour and the social position of that individual within the herd.

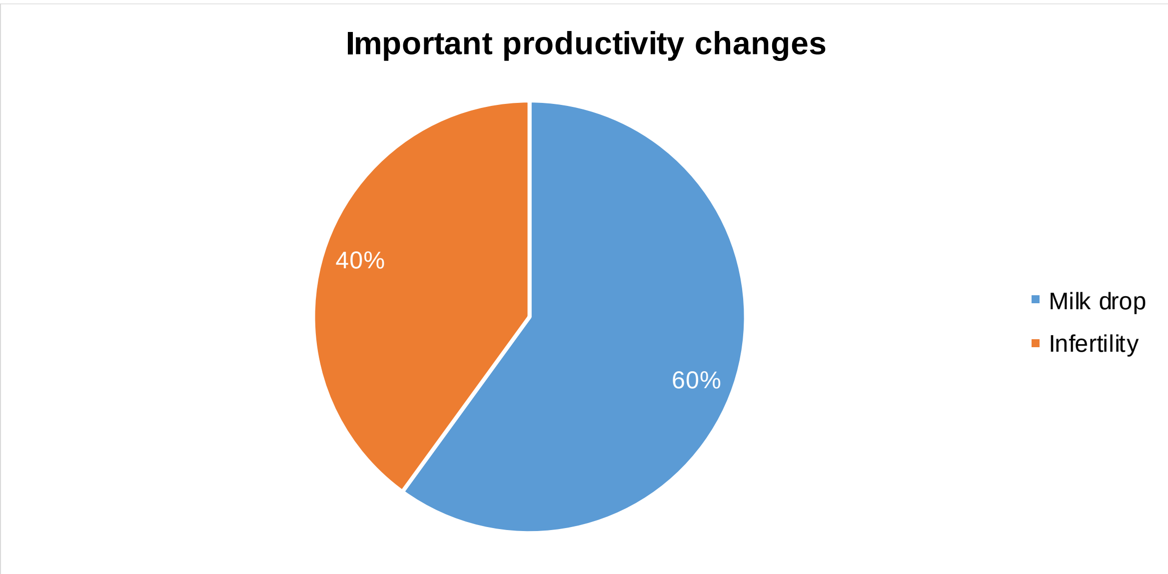

Figure 10: A pie chart to show the changes in productivity mentioned by the experts. This figure shows the important changes in productivity experts look for when identifying a lame cow. Out of the 5 responses given, a drop in milk yield was the most common identifier mentioned by the experts.

3.3.2.2. Identifiers of a chronically lame individual

The second question asked the experts if they had access to any aspect of a cow's behaviour or physiology, what they would look at when identifying chronic lameness.

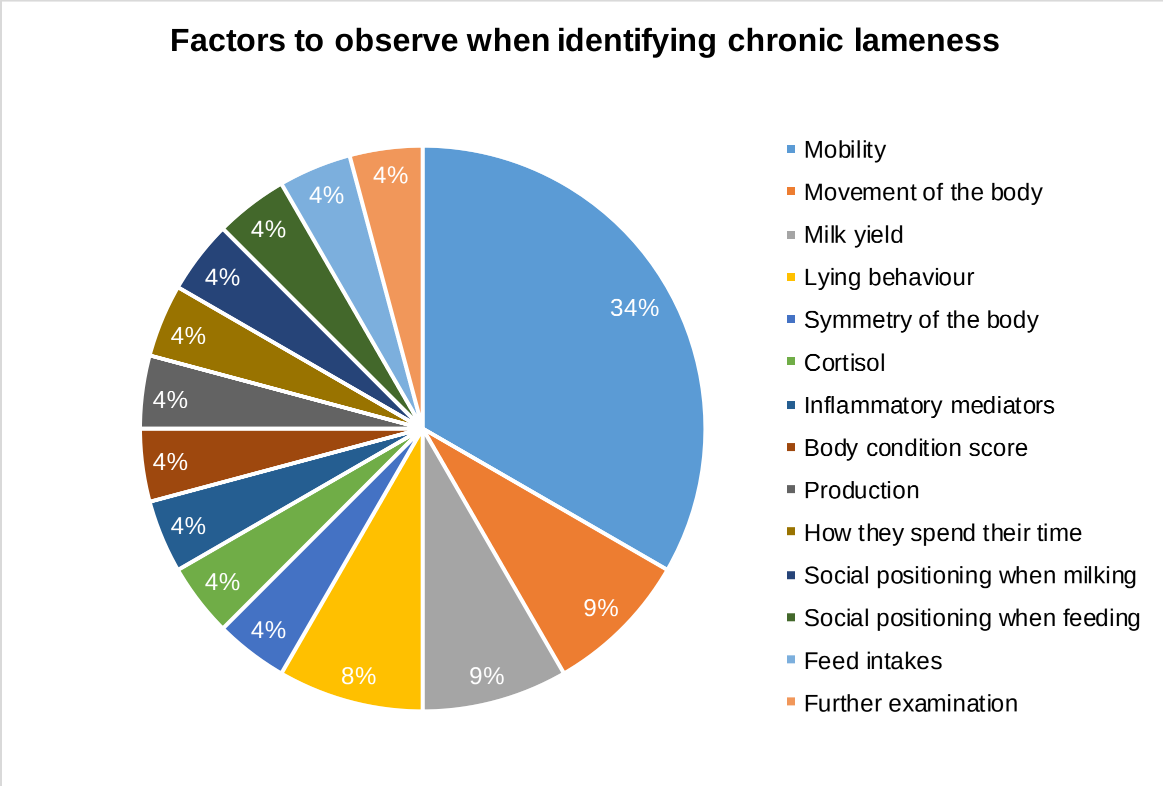

Figure 11: A pie chart to show all the variables mentioned by the experts when asked what they would look for to identify chronic lameness. This figure shows the different variables experts would look for when identifying chronically lame individuals. 24 responses were given, revealing mobility as the most common variable that experts would look for, followed by the general movement of the body, milk yield and lying behaviour.

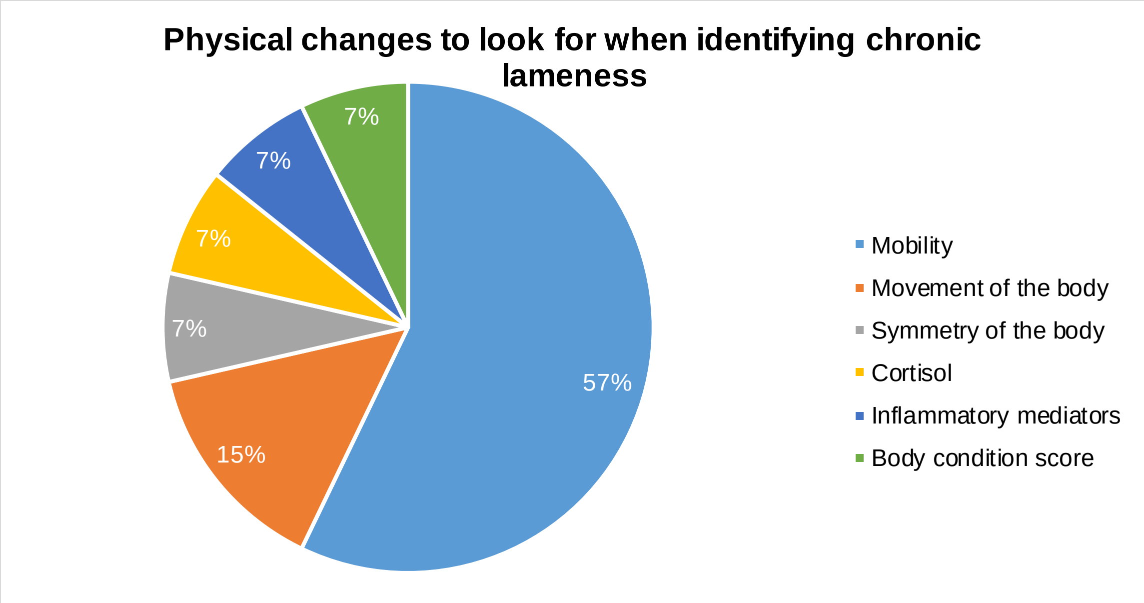

Figure 12: A pie chart to show the different physical changes experts would look for when identifying chronic lameness. The most common identifier experts would look for, out of the 14 responses given, is a change in mobility; they would look at regularly mobility scoring cows, preferentially with an experienced scorer, in order to identify a chronically lame cow.

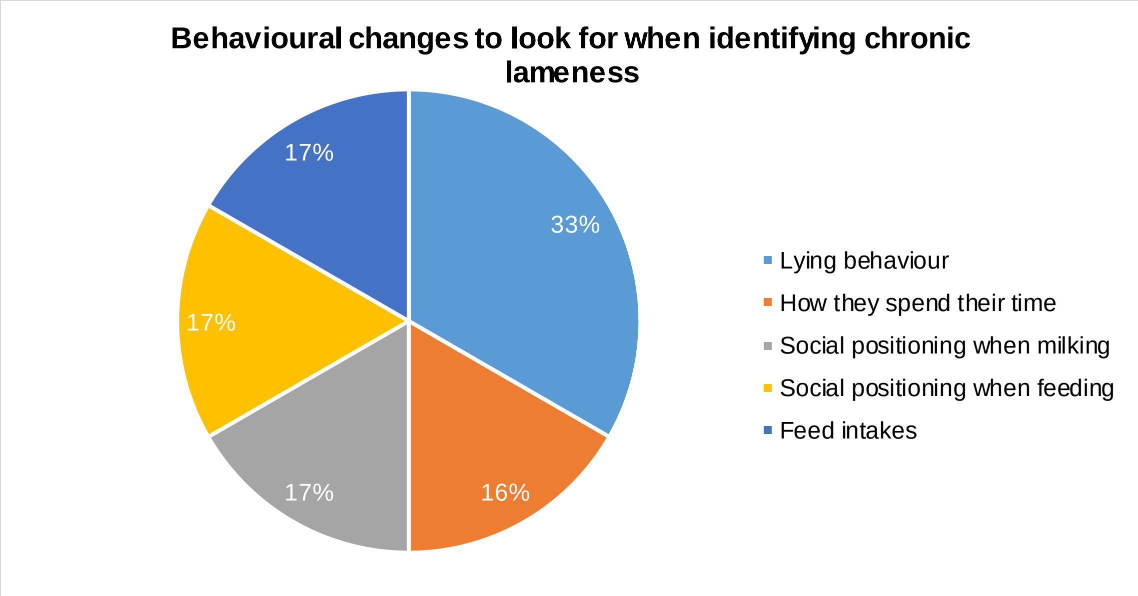

Figure 13: A pie chart to show the different behavioural changes experts would look for when identifying chronic lameness. If given data on all aspects of a cow's behaviour, out of the 6 behavioural variables chosen, lying behaviour was the most common variable mentioned by the experts. For the purpose of this analysis, lying behaviour includes the number of lying bouts and the duration of these bouts. One expert specified that it was also a deviation from their normal lying behaviour that was important, not whether lying bouts exceeded a certain value.

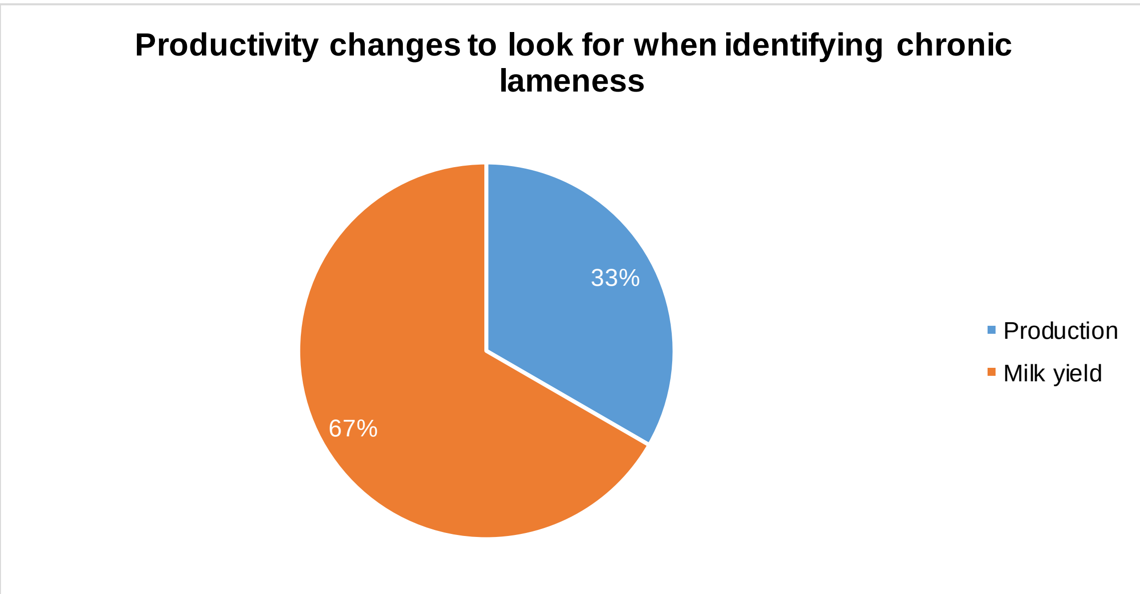

Figure 14: A pie chart to show the different productivity changes experts would look for when identifying chronic lameness. Out of 3 productivity changes given, a reduction in milk yield was the main change in productivity that experts would look for.

3.3.2.3. Defining chronic lameness

When asked how experts would define chronic lameness, a variety of responses were given. In general, this question was the one most participants struggled to answer succinctly, with many confused with how they would begin to add a time frame for an acute case to become chronic.

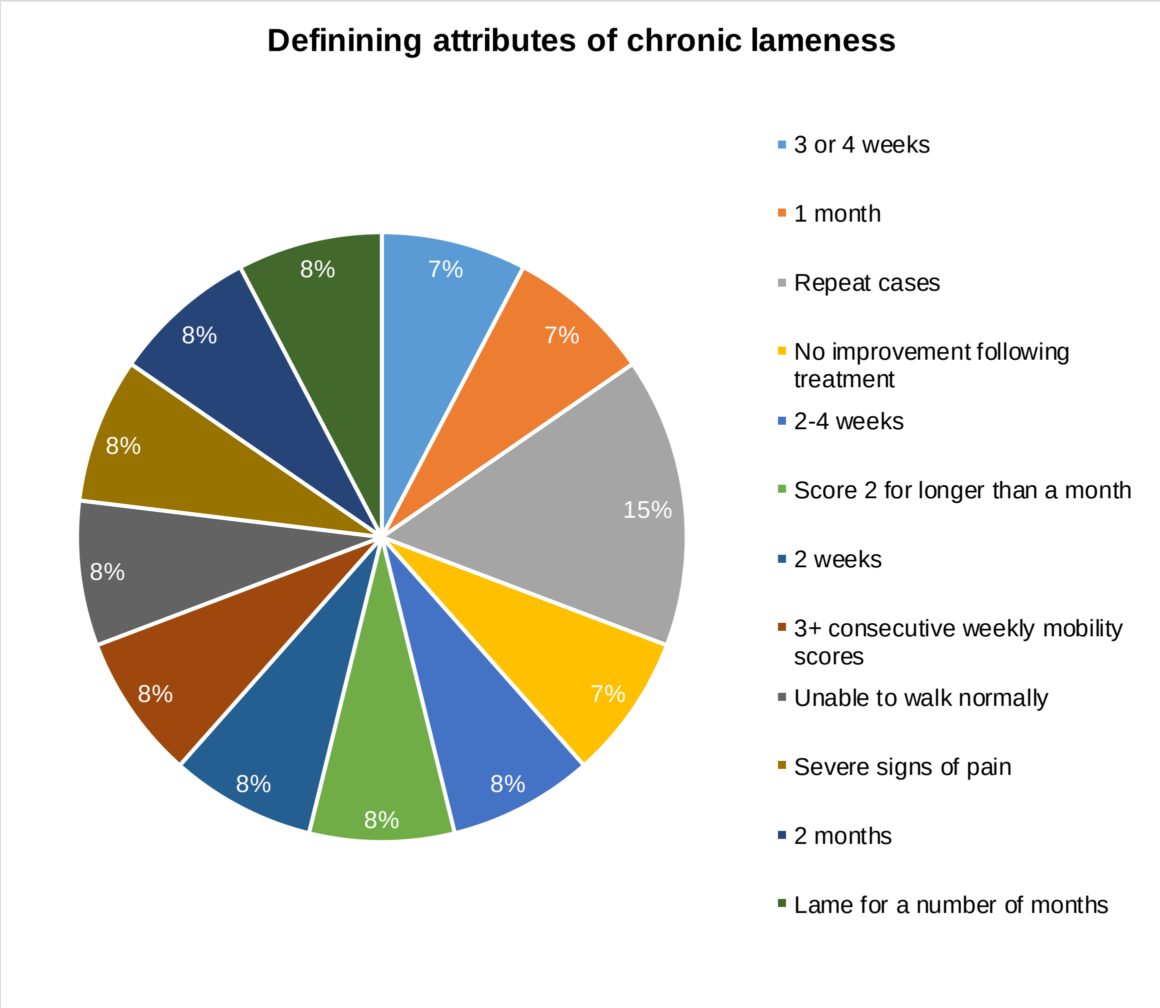

Figure 15: A pie chart to show the defining attributes of chronic lameness. The results show that, with 13 responses given, every expert gave a different answer when asked "how would you define chronic lameness?" Repeat cases of lameness was the only defining attribute that was mentioned by two individuals, with all other experts giving different answers.

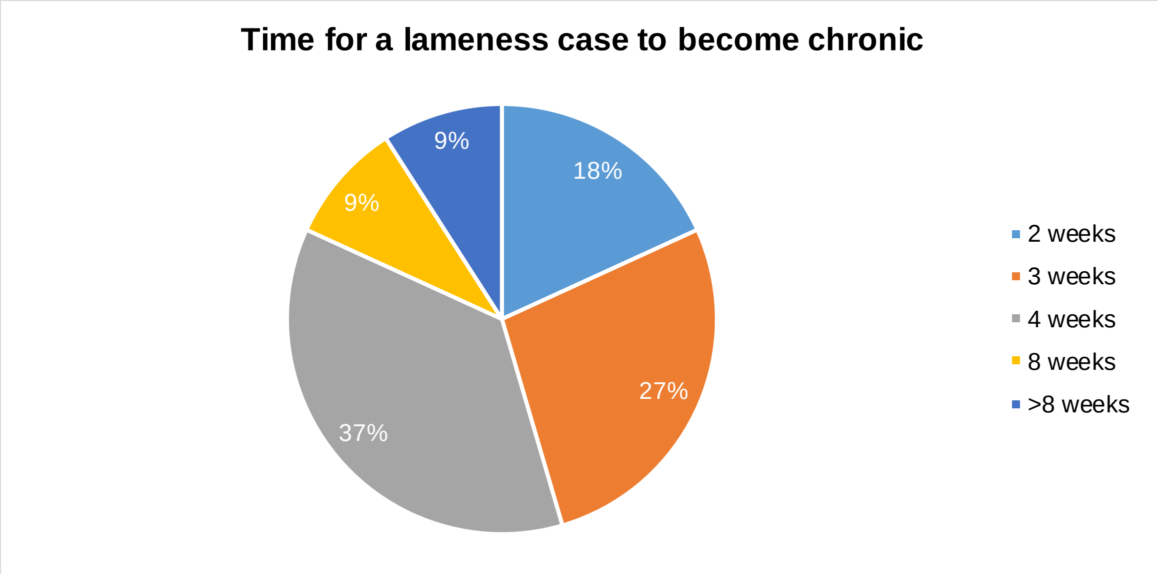

Figure 16: A pie chart to show the timeframes given for an acute case of lameness to become chronic. In order to gain clear timeframes from the experts, the responses were organised into weeks, to present the answers in the same unit. Some interpretation of meaning was needed as most experts struggled to come up with a definite answer. If an expert gave an answer such as “2 to 4 weeks” the response was recorded in each category; 2 weeks, 3 weeks and 4 weeks. The answer “lame for a number of months” was interpreted as more than 8 weeks. While interpretation of the answers may not necessarily accurately represent their meaning, it was an important step to highlight the most commonly stated time for an acute case to become chronic. This step gave 5 timeframes, with 4 weeks the most frequently mentioned time for a cow to become chronically lame.

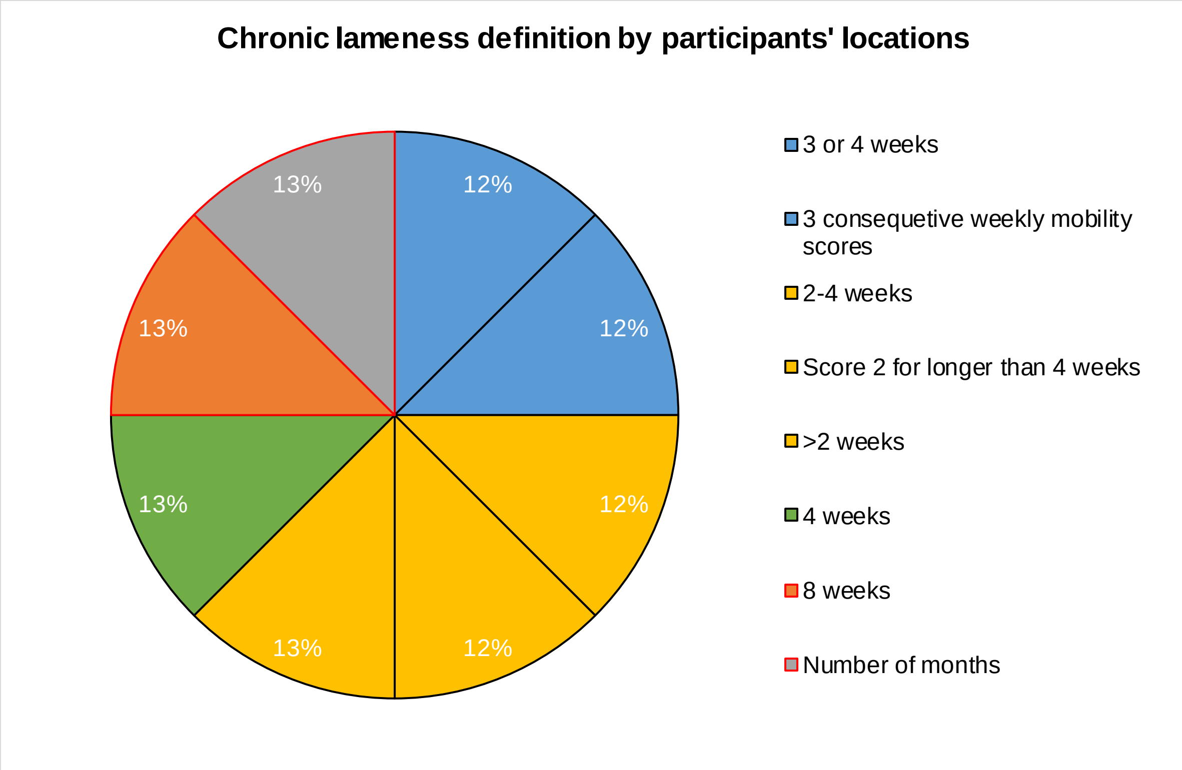

Figure 17: A pie chart to show the timeframes given for an acute case of lameness to become chronic, based on participants' work place. The confusion among experts when asked how to define chronic lameness can be further illustrated by grouping the responses by the 8 participants' places of work. The segments of the pie chart above, which are the same colour, represent the participants who work at the same place. As you can see, even colleagues have different opinions, with no two participants giving a clear timeframe for an acute case of lameness to become chronic. The borders around each segment represent whether that individual is a qualified veterinarian or an academic. The 2 academics (red border) gave the longest timeframes, compared with the qualified veterinarians or veterinarians that were in academia (black border).

3.3.2.4. Pros and cons of the mobility score

As this project is looking at developing a new diagnostic tool, in most interviews it was interesting to get an understanding of how the experts would personally evaluate the mobility score. As the participants were all based in the UK, the mobility score evaluated was the AHDB Mobility Score (AHDB, 2013)

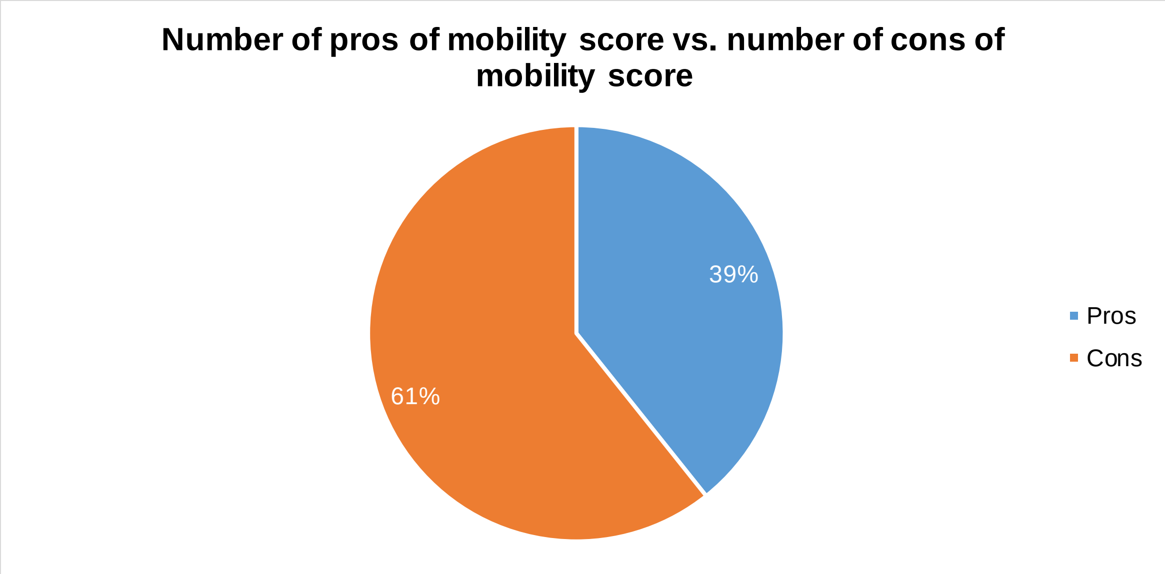

Figure 18: A pie chart to show the number of pros that were mentioned by the experts, vs. the number of cons, when evaluating the AHDB mobility score. The results show that, of the 28 responses given to evaluate the mobility score, 61% represented the cons and only 39% represented the pros.

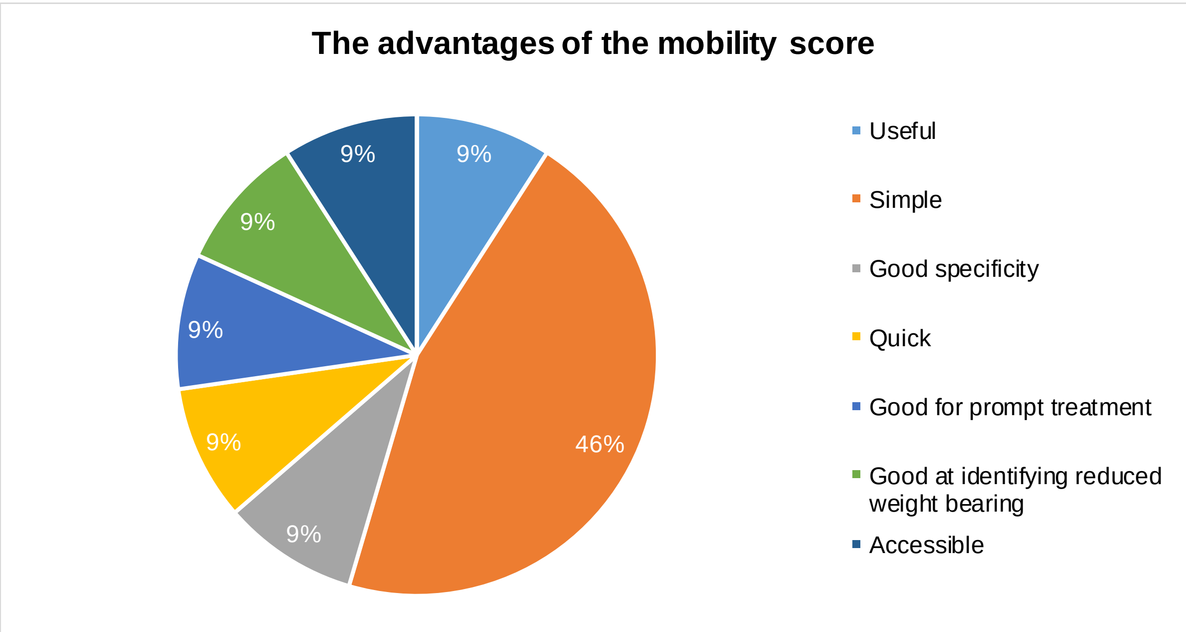

Figure 19: A pie chart to show the different advantages of the mobility score, mentioned by the experts. The results in the pie chart show, of the 11 pros given, the simplicity of the mobility score was the most commonly mentioned advantage. The word "simple" was used to represent how easy the score is to use, how easy it is to explain to others, and how it is a "good, blunt instrument" for identifying lame cows. The interviews were interpreted using the umbrella term "simple" to account for differences in terminologies used by individuals.

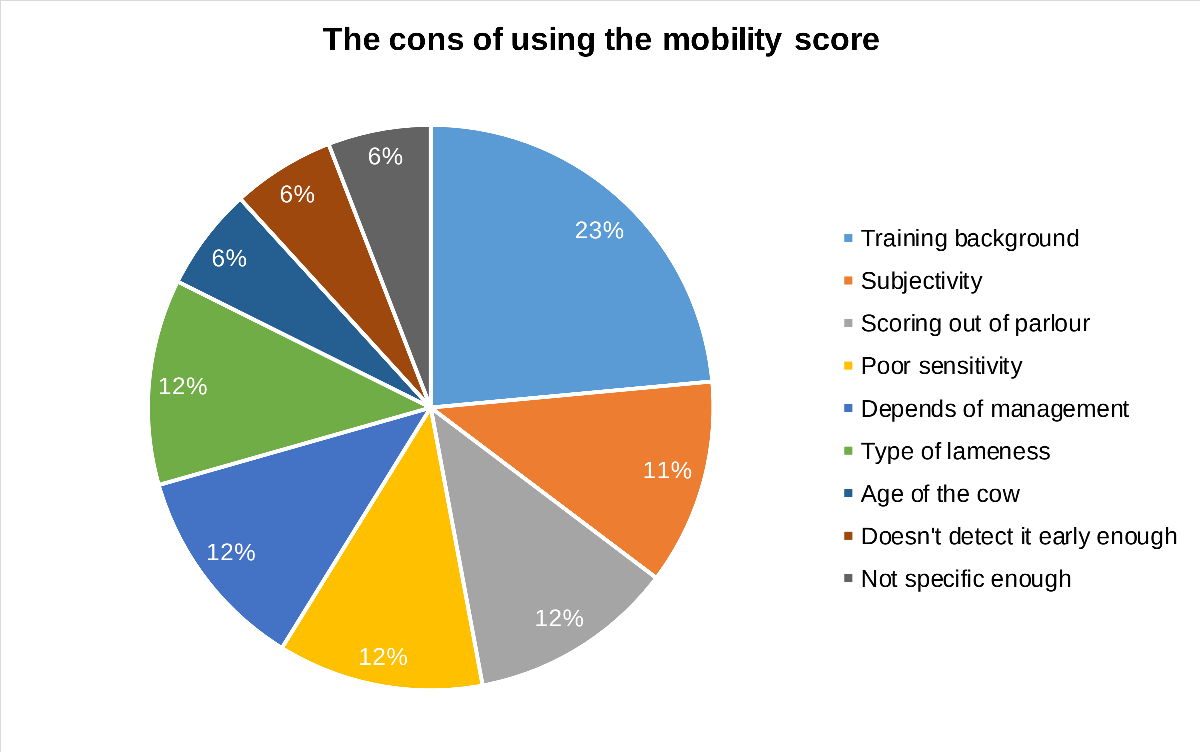

Figure 20: A pie chart to show the different disadvantages of the mobility score, mentioned by the experts. Of the 17 mentioned cons, training background of the scorer is the most commonly mentioned disadvantage. The training background includes how different scorers may use the score differently, how they identify milder cases of lameness and how frequently they update their training, as their judgement could drift over time. The category “Depends on management” incorporates the floor surface cows are walking on when they are scored, and whether a footbath is used prior to scoring. “Types of lameness” includes bilateral lameness and cases of digital dermatitis; as this lesion may only cause pain when knocked, and therefore, may not be recognised using the mobility score.

4. Discussion

Animal welfare is a topic that has seen a dramatic increase in coverage over the past 30 years, reflecting our society's growing interest in the way we manage livestock (von Keyserlingk and Weary, 2017). Since the release of Harrison's book, Animal Machines (1964), societal input has motivated governments to implement policies to improve the way in which we look after our animals (von Keyserlingk and Weary, 2017). This influence extends beyond policy decisions, with the execution of innovation also relying on the approval of the general public and industry professionals (Weary *et al.*, 2016). Science cannot work in isolation, cooperation with social science research is necessary for progress to be made (von Keyserlingk and Weary, 2017; Weary *et al.*, 2016; Weary and von Keyserlingk, 2017). Ideas must resonate with the general public and livestock producers in order for them to be successful (Weary *et al.*, 2016).

The demand for change is clear in the dairy industry (Barkema *et al.*, 2015). For change to be effective, this project acknowledged the need for collaboration, using a social science approach to enable the implementation of a science-based innovation. The two complimentary studies that form this project will be discussed separately, before they are considered as a whole.

4.1. Is there an alternative method to identify lameness?

Section 1.5 highlighted that electronic sensors are becoming the favoured option in veterinary medicine for disease diagnosis. An advantage of sensors, designed by companies such as CowAlert (2018), is they can continuously monitor a cow's behaviour and health status through a motion sensor attached to the leg. The collection of mobility data builds up an individualised picture of the cow's mobility, enabling the veterinarian, or farmer, to easily identify when a cow is in danger of going lame (CowAlert, 2018). This is a novel technique that is likely to increase in popularity as the technology decreases in price.

However, there is still a long way to go. One of the participants who took part in the pilot study of the consultation, when asked "*Do you think that electronic sensors will be the way to go in terms of monitoring lameness on farm?"* responded with *"I kind of get the feeling that we haven't really come up with the right electronic sensor yet. Whether it's a force plate or whether its thermal imaging or sort of activity changes, it's making that practical in the on-farm situation as well as reliable, valid and something farmers will buy into and respond to. I think there's loads of scope there, but we are a long way off a best system yet."* This response is in line with the number of participants who, even if given access to every aspect of a cow's behaviour and physiology, would stick to mobility scoring (see Fig. 11). To quote another participant *"I'm not convinced that the reliability of other measures is good enough".* There is a loyalty to the mobility score that is currently preventing the universal implementation of electronic alternatives.

These responses are in line with this project's aims as it recognised the current gap in the field of lameness research, where the flaws of the current method are recognised, but the technology of future advances are not yet able to fill the gap. There seems to be a need for a middle ground, a technique that will improve the mobility score, without alienating the farmers and veterinarians from their blunt instrument of choice.

4.1.1. General evaluation of the proposed diagnostic

To avoid alienating the professionals the core aspect of this proposed diagnostic had to be the mobility score. The mobility score has some obvious advantages, it is quick, easy to explain and easy-to-use; but it is also flawed by scorer interpretation and level of training. By including other aspects of a cow's behaviour and physiology, the limitations of the mobility score could be alleviated (Hanmandlu *et al.*, 2011).

The combination of the chosen variables provided strong AUC results in the ROC analysis for Herd 1, with 5 out of the 6 dates showing excellent AUC values (see Table 6). This means the scoring system was able to detect a lame individual, as determined by a mobility score of 2 or 3. As shown in Fig 4. the scoring system also highlighted the spread of lameness scores among cows categorised by the same mobility score. This shows how varied the presentation of lameness can be, with each cow showing an individualised physiological response.

The variables used in this study were chosen for two reasons; they were already monitored and recorded on farm, and they had a reported association with lameness in peer reviewed scientific papers. While the results from the consultation will be able to direct future research, for this study its results did not influence the development of the scoring system. This presents the first limitation of the diagnostic developed. Although the literature referenced all the variables chosen in the score, they may not be what the experts would universally include. Milk yield is a prime example of this. Although research states milk yield lowers in lame cows (Reader *et al.*, 2011; Van Hertem *et al.*, 2013; Archer *et al.*, 2010), in reality the cause of this change is complicated to elucidate. As lameness often impacts higher yielding cows (Archer *et al.*, 2010), they could be reporting an average yield instead of their usual, high milk yield. The complex association between milk yield and lameness could be why the bivariate correlation analysis revealed, for a number of months, a poor correlation between milk yield and lameness score (see Table 4 and Table 7). To test whether milk yield negatively influenced the accuracy of the score, it was removed as a variable and the analysis was performed again. While the strengths of the correlations improved, there was very little difference between the AUC values, with the original diagnostic proving to be slightly more accurate (see Table 12).

Another factor that could have influenced the success of the scoring system is the definition of an "optimal" BCS. As a simple, linear classification was used to categorise the values before they were combined it ignored the fact that a BCS over 4 is also an indication of poor health (AHDB Dairy, 2018). With more time, a more intuitive code could have been written to tailor the way the values were binned. However, as the main correlation to lameness is a low BCS, the effect was negligible based on the strong correlations found.

In order for it to fit the brief of being an easy-to-use method, further development of the code is required to ensure the farmer has minimal work to do to get the results needed. In this study, the row number on Excel had to be typed into MATLAB to get a lameness score for the corresponding cow. With 400+ cows in a herd, finding the row number would be a time-consuming process. However, with further improvement this issue can be rectified, and the code can be tailored so the farmer simply enters the cow's ID number to return their lameness score.

In the study by Van Hertem et al. (2016), a generalised linear mixed model (GLMM) was developed as the same herd was locomotion scored 41 times over the course of the study. In this study, in the place of GLMM, multiple linear regression was used. While this method still tested the predictive ability of the five indicator variables, a repeat measure may have been more reliable. Future research should base the model on a more reliable dataset, preferably collecting data alongside the study so all variables can be collected for each cow in the herd, at each time point. The data from Herd 1 was however, a reliable source for this project, as the majority of the herd was scored at each time point. Furthermore, the difficulty faced when trying to source a consistent data set is not a fault of the researcher but of the inconsistent way data is collected and stored on farm.

A difficulty in developing a new scoring system is how its accuracy had to be measured against an already questionable method, the mobility score. As the mobility score is the only trusted tool available to identify lameness it was used to measure the success of the proposed lameness score. This makes it very difficult to evaluate the lameness score for two reasons. Firstly, the AUC results for Herd 1 could have been positive because the mobility score was included, so in essence the mobility score was compared against itself. Secondly, as the lameness score got good AUC results it could suggest that it is predicting the same thing as the mobility score and therefore, it loses its need. To properly evaluate this method, and to begin to define the parameters of what is lame, further tests will need to be conducted to identify the point at which the lameness score exceeds the capabilities of the mobility score. Confidence can be taken in the knowledge other studies would face the same limitation; as the mobility score is the gold standard practice in lameness identification it is often used to evaluate new methods (Van Hertem *et al.*, 2016).

While this method has some limitations, they are predominantly issues of the available data and the novelty of the scoring system. This study should be viewed as a preliminary test, from which improvements can be made. The score shows the potential to expand the mobility score and offer more information to the farmer or veterinarian, and is an important step in bridging the gap in defining what is non-lame, lame and chronically lame.

4.1.2. Can the diagnostic finesse the mobility score?

To address the necessity for a simple solution to a complicated problem, the first aim of this scoring system was to see if it could finesse the widely used mobility score. As the issues lay in its limited scale and observer error, including other factors proved promising. While the success of the lameness score was limited by its comparison to the mobility score, the raw data did show some interesting results. When presented graphically, it was often the score 1 cows that had the greatest range of lameness scores (see Fig. 4). This supports the evidence that mildly lame cases are the harder ones to detect using the mobility score alone and that score 1 covers a range of factors (Reader *et al.*, 2011; Green *et al.*, 2014).

There is no reason to rule out this diagnostic based on the results shown. It is possible, with further development, and collaboration with lameness experts, that the diagnostic could be tailored to identify lameness earlier than the mobility score. The best way to take the lameness score forward would be to monitor the same herd of cows over a period of a few months, using both the mobility score and the lameness score. Using one, experienced, mobility scorer to score the cows, the issues of reliability could be minimised. If the lameness score flagged an individual as lame before the mobility score, then a veterinarian could check this cow to confirm if the lameness score was accurate or not. The issue of using historic data is that we cannot comment on the reliability of the data or confirm if that cow is lame or not. Once there is evidence the lameness score can identify lame cows, the parameters of what is severely lame, mildly lame, and healthy can be defined. After the score has been developed and parameters have been identified, the score will be an easy-to-use method for the farmers as all they'll be required to do is continue to collect the data they already record on farm, input it into a computer and view the results.

An added benefit of the lameness score is that farmers are only required to use the mobility score, therefore, human capacity of only being able to judge 7 categories is unimpeded (Miller, 1956; Deolekar and Morris, 2003). With the inclusion of other variables, the lameness score serves to preserve the inter-observer reliability of the mobility score, whilst simultaneously transmitting more information (Deolekar and Morris, 2003). The score is not asking more of the farmers, it simply requires other variables, which are already recorded on farm, to be included in the measurement. This is an efficient use of available information and provides a more extensive summary of a cow's health.

4.1.3. Can the diagnostic replace the mobility score?

In short, potentially. The previously discussed limitations of the lameness score, mean that at this stage of development, it requires the inclusion of the mobility score in order to get successful results. This was confirmed when the analysis for Herd 1 was re-run with the mobility score removed (see Section 2.3.4). None of the AUC results were successful, showing how the lameness score cannot identify lame individuals, without the inclusion of the mobility score. This could be due to the previously mentioned limitation of the ROC analysis, which suggests the lameness score predicts lame cases solely because it includes the measure used to compare it against. The reliance on the mobility score further highlights a need for a more reliable scoring system to identify lame cows.

Without further development of the method it is difficult to determine the diagnostic ability of this scoring system. Based on the literature that states a combination of variables is more beneficial (Hanmandlu *et al.*, 2011) and the graphical representation of variance between individuals (Fig. 4), the score still has a value proposition worth pursuing. At this stage, however, the main focus should be to broaden the capabilities of the mobility score, to provide a stepping stone between the mobility score as it is today and the electronic sensors of the future.

4.2. What is the expert opinion on lameness in dairy cattle?

To ensure the successful future development of the proposed multivariate system, it was necessary to collaborate with multiple stakeholders. As already mentioned, for innovation to be successful it cannot work in isolation, to mitigate the limitations mentioned in the previous section, it was important to get the opinion of others.

This project chose to interview the individuals that treat and observe lame cattle on a regular basis, the veterinarians and researchers. As mentioned in Section 3.2.1. the purpose of the consultations was two-fold: to identify any variables, currently not measured on farm, which would be useful in identifying lame individuals; and to highlight any discrepancies between the participants' definitions of lameness, revealing areas in need of further research. This study aimed to corroborate the aforementioned pitfalls of the mobility score (see Section 1.4.1) and highlight how a universal definition of chronic lameness is both lacking and necessary.

4.2.1. General evaluation of the consultation

The consultation was successful in meeting its two main aims. It identified different variables of importance, which could prove useful in the identification of chronic lameness (see Fig. 11); and it highlighted areas which required further research, such as how to define the time frame for a case of lameness to go from acute to chronic.

The consultation's intended form was a semi-structured interview, as this method provided a greater scope for more natural conversation. However, due to extraneous factors, such as the location of the participants' work place, and their available time, 7 out of the 8 interviews were conducted over the phone. The combination of these two factors may have removed the element of spontaneous conversation in some interviews. With more time it may have been possible to tease apart participants' responses and delve deeper into why they answered the way they did.

Furthermore, the descriptive nature of the way some participants answered the questions, made it difficult to code the responses using NVivo. A combination of NVivo and interviewer interpretation had to be used to code the participant's meaning and record their responses quantitatively. The need for interpretation could have introduced some bias into the results, however, considering the specific focus of this study and the directed nature of the questions, the influence of bias would have been minimal.

A further limitation of the study was the different way participants understood "important" in the question, *"From your experience of how lameness presents itself in dairy cows, what are the most important changes that are displayed in a lame cow?"* Participants questioned the intended context; whether it meant "significant", or "obvious". In some instances, "important" was "obvious", in others "important" was how strongly that change correlated to lameness. As a strict script was not used, depending on the way the participants queried the question, different pointers were given. It was difficult to avoid this as, for the purpose of this study, it was more valuable to see what their initial response to the word "important" would be; whether to them the obvious changes were more meaningful, or whether they considered subtler changes to be more significant. As a result, this question was not changed from the pilot studies. However, as most individuals listed "impaired mobility" as an important change (see Fig. 8 and Fig. 11), the difference in interpretation couldn't have been that great.

Even though an attempt was made to avoid leading participants' answers, there were a few reasons why this may not have been successful. The semi-structured approach led to the questions being phrased slightly differently each time. For example, sometimes the question, *"If you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? For example, would you follow the current procedure of mobility scoring them, or would you include other indicators?"* included the word "just" before "mobility scoring". Asking participants if they "just mobility score" may have caused the participants to think that this practice was insufficient in identifying lameness, leading them to give an answer they may not have given otherwise. However, as experts in the field it is unlikely they would have been swayed by this inflection.

Another factor that could have led the participants' responses was the information sheet given to them prior to the study. By knowing the study's aim was to identify any subtler changes not yet recorded on farm, the participants could have been led to prepare answers before they were interviewed. However, as some participants only gave the mobility score as the tool they would use to identify lameness, the experts were comfortable giving true responses, as some did not deviate from the current procedure.

The sample used for this study could also be a limitation of this study as it was a relatively small group of individuals, which only included veterinarians and researchers in the field of lameness. If this research was taken forward, conducting more interviews and targeting a wider range of individuals would prove interesting. Future analysis could look into the opinions of others in the field also, to see if farmers and foot trimmers would agree with the answers given or if they would have a different opinion. By increasing the diversity of the sample, and the sample size, appropriate statistical tests could be used to provide the results with greater quantitative support. However, for the number of questions asked, and the aims of this particular study, the sample size was sufficient.

4.2.2. Important variables to consider

Despite the limitations of the consultation, it complimented the scoring system as it identified ways in which it could be improved for future use. One key limitation of the mobility score is how it only looks at the physical presentation of lameness. While many experts agree that physical changes are important to identify, with impaired mobility being a commonly mentioned determinant of a lame individual (see Fig. 7 and Fig. 8), behavioural aspects could also be of some use. By working in tandem with the second study, the consultation highlighted how there are other variables that could be included in the score, which are currently not measured regularly on farm. From behavioural changes, such as lying times, to different physical presentations of lameness such as the adduction and abduction of the limbs; it is evident the experts note more changes in a cow than just a change in mobility. While mobility remains the most popular variable, there is scope for expanding the score to gain a more holistic view of lameness. This insight can be applied to the diagnostic tool as it is developed further.

Interestingly, productivity changes were less important to the experts, only mentioned 3 times in total. This contrasts with what is said in the literature, as milk yield (Reader *et al.*, 2011; Van Hertem *et al.*, 2013; Archer *et al.*, 2010) and fertility

(Melendez *et al.*, 2003; Newcomer and Chamorro, 2016; Lucey *et al.*, 1986; Archer *et al.*, 2010) are often quoted as important changes seen in lame individuals. While some said milk yield was an important variable to consider, others disagreed, with one participant saying *"milk drop is not really fair because we know that happens but…that's not something I would particularly focus on because they often do keep milking quite well."* Taking into consideration the results from the bivariate correlation analysis (see Table 4 and Table 7), this project has found a weak association between milk yield and lameness, and therefore, it may be unnecessary to include this variable in future developments.

The important point to take from the variables identified in the consultation, is the number given by each participant. As can be seen on Fig. 11, in most instances, more than one variable was mentioned by the experts. This highlights the shared opinion that looking at multiple different aspects is beneficial when identifying complex diseases; and corroborates the idea that looking beyond mobility would serve to improve lameness identification.

4.2.3. Defining chronic lameness

While experts may have agreed on the benefits of identifying multiple changes displayed by a cow, the consultations showed disagreement among individuals, working within the same occupational sphere, when asked to define chronic lameness (see Fig. 16 and Fig. 17). Even though the selection of participants have published over 300 scientific papers between them, the results from this question showed the difficulty they face when presented with the issue of chronic lameness. Its complexity is shown in the fact no real defining attribute was identified above others; even timeframes had to be manipulated to find a common denominator. The consultation identified a large gap in our understanding of lameness – without a universal definition among the experts of this field, how can an effective treatment plan be determined?

The consultation also highlighted how the experts' opinions are at odds with current practice on farm. To quote one of the participants *"In a retailer's scheme we've defined it* (chronic lameness) *as 3 months…. 3 months is to give the farmer, the producer, every chance of getting that cow recovered."* While the notion of allowing recovery is justifiable, as evidence suggests cows experience chronic pain (Whay *et al.*, 2005), the likelihood is these cows won't recover but will be left to experience high levels of pain for an unacceptable duration. As most experts quoted a month as the cut-off period for cows to transition from acute to chronic lameness, the retailer schemes need to be in line with the current consensus. It is also interesting to note that the academics gave longer timeframes than the qualified veterinarians (see Fig. 17). It would be beneficial to interview more academics (as this study only interviewed 2 academics who weren't qualified veterinarians) to see if this trend is mirrored in a larger sample size.

4.3. The future of lameness

The results from the analysis of the diagnostic tool, and the consultation show two areas the industry needs to address. Firstly, the industry needs to acknowledge that, although the mobility score has many advantages and is a robust, easy-to-use method, there is potential for improvement. Secondly, chronic lameness needs to be recognised in the literature as a potential consequence of failing to resolve mildly lame cases. A universal definition is needed so all parties concerned, from farmers to veterinarians, know the difference between an acute and chronic case of lameness. While there will always be cows that are difficult to categorise, with many different presentations of lameness causing confusion, a start needs to be made in recognising the symptoms earlier to prevent the animal suffering.

The future of lameness ultimately relies upon the improvement of two things; prevention and treatment. In order to successfully address the issue of chronic lameness, researchers need to establish what method should be universally employed to identify cows in early stages of lameness, and how these cows can be treated effectively.

4.3.1. Prevention

Through use of the existing literature, this research project has identified variables that are commonly recorded, and that are labile enough to indicate changes in dairy cattle health and production and incorporated them into a novel scoring system. However, taking the opinions of the experts into consideration, and the conflicting results found in the diagnostic analysis regarding milk yield, this project has highlighted a need for more empirical evidence to work out the multiple aetiologies of lameness and how they interact. With a greater, more conclusive understanding of how lameness develops, preventative techniques can be more targeted.

Obtaining objectivity is becoming increasingly easier as genomic technology advances our understanding of disease. There is already evidence to suggest cows are predisposed to lameness issues and problems of mobility (Kougioumtzis *et al.*, 2014); if we are able to identify other heritable factors we will be more equipped to predict a change before the cow expresses it. There is no reason to suggest why genetic heritability cannot be incorporated into future iterations of the multivariate scoring system, as this information may provide valuable insight into a potential predisposition to lameness.

4.3.1.1. Lameness heritability

To understand how lameness can be prevented, it is interesting to first understand the origins of the condition, and whether it can be passed from generation to generation. Research has already identified two examples of heritable factors associated with lameness, body condition and body weight (Kougioumtzis *et al.*, 2014; Kock *et al.*, 2018; Berry *et al.*, 2003). With genomic research, scientists have identified a genetic element to these predominantly environmentally driven factors, highlighting cows that are predisposed to maintain optimum body condition and therefore, protect themselves from locomotor issues such as lameness (Kougioumtzis *et al.*, 2014). It makes sense for the inheritance of these factors to lead to lameness, as studies have shown how cows with stable body condition scores are less susceptible to the condition and exhibit healthier mobility (Kougioumtzis *et al.*, 2014) (see Section 1.3.2). It is interesting to consider evolution and note how this predisposition to low body condition and subsequent lameness may have arisen.

4.3.1.2. Epigenetics

At the 2018 Cattle Lameness Academy seminar (2018), Dick Sibley, Chair of the National Mobility Steering Group, highlighted that lameness is not inevitable – cows' feet are evolutionarily designed to withstand the forces transferred when they walk. Over the last 50 years, the industry has seen improvements in animal productivity through selective breeding (Ibeagha-Awemu and Zhao, 2015). However, with intensification of farming occurring over the past century, there has been a historic focus on increasing the gross income per cow to improve the net profit (Zwald *et al.*, 2004). The short-sighted emphasis on the bottom line meant cows were selected based on milk yield alone, a selection that has since influenced the development of disease (Shanks *et al.*, 1978). It is clear in the literature that it is the higher yielding cows that are more at risk of developing lameness (Archer *et al.*, 2010). Therefore, selective breeding is one way in which we may have indirectly altered a cow's susceptibility to welfare issues, such as lameness. With consumer awareness of animal welfare increasing and with profit margins reducing, there is a growing need to identify genetic correlations between disease and productivity to optimise selection that will benefit both cows and the farmers' income (Van Dorp et al., 1998).

While it is plausible our farming practices have proliferated the diseases that are precursors to this symptom (Kougioumtzis *et al.*, 2014), the transgenerational impact of lameness can only be partly explained by genomic information (Jian *et al.*, 2010; Haile-Mariam *et al.*, 2013), with heritability also influenced by the epigenome (Ibeagha-Awemu and Zhao, 2015). While there is no evidence describing the role of epigenetics in the development of lameness, this project argues poor farm management and selective breeding for profit has led to epigenetic alterations, which have consequently predisposed cows to the condition.

The study of epigenetics looks at deciphering the relationship between nature and nurture by observing the biological consequences caused by changes in the environment (Carey, 2011), such as nutrition, climate and disease (Ibeagha-Awemu and Zhao, 2015; Guozhong *et al.*, 2014). It encompasses stable and/or heritable changes in gene function, with no alterations to the DNA sequence (Denk and McMahon, 2012). Epigenetic modifications change the expression of a gene through varied molecular modifications, changes which can subsequently be passed on from cell-to-cell during cell division (Carey, 2011). There is evidence to suggest the existence of an "epigenetic language", a network of communication with the purpose of regulating cellular processes such as repair, transcription and replication (Selvi *et al.*, 2010). The epigenome is generated by processes, which work in conjunction, to form a self-propagating regulatory network that acts to alter the phenotype of an animal (Selvi *et al.*, 2010; Triantaphyllopoulos *et al.*, 2016). The most studied epigenetic mechanisms are DNA methylation and post-translational histone modifications (Triantaphyllopoulos *et al.*, 2016).

Over the past few decades, since its conception, our understanding of epigenetics has evolved. From simple covalent modifications that open and close genetic material, to signals with the ability to orchestrate gene expression (Selvi *et al.*, 2010). Epigenetic modifications have the potential to both directly influence the development of the individual via acute epigenetics; and indirectly affect the development of that individual's offspring via transgenerational epigenetics (Singh *et al.*, 2011). This project poses the potential of epigenetics to fill in the gaps in our understanding, and hypothesises an epigenetic component to chronic lameness, which if identified, could ensure prevention for future generations.

4.3.1.3. The future of selective breeding

By identifying genetic elements associated with lameness, prevention of the condition can be achieved through positive selective breeding (Kougioumtzis *et al.*, 2014). Historically, breed improvement has relied on selecting for certain, desirable phenotypes (Ibeagha-Awemu and Zhao, 2015). However, the issues raised in the previous section show how the selection of one trait, may have negative influences on other aspects of animal performance, and their offspring. This is due to the phenotype being influenced by multiple interactions between the environment, genotype and epigenotype (Ibeagha-Awemu and Zhao, 2015). The epigenotype, has a direct and indirect influence on health, growth and reproduction (Ibeagha-Awemu and Zhao, 2015). The study of epigenetics offers a potential improvement to animal breeding and should be considered in conjunction with genetic information; especially as epigenetic marks, such as histone modifications and DNA methylation, are heritable and influence performance indicators in dairy cows, such as lactation (Triantaphyllopoulos *et al.*, 2016; Singh *et al.*, 2010; Ibeagha-Awemu and Zhao, 2015).

While there is growing evidence to support epigenetic perturbations in the aetiology of disease, evidence is lacking in the field of livestock diseases (Ibeagha-Awemu and Zhao, 2015). Increased funding and research are needed to understand the epigenetic influence on disease traits and economically important livestock phenotypes (Ibeagha-Awemu and Zhao, 2015). With greater understanding, selection of beneficial traits can consider the influence of the environment, genotype and epigenotype as interlinking factors, rather than separate entities.

In terms of taking this project forward, the study of epigenetics could explain the complicated association between milk yield and lameness, and may be an important factor in the aetiology of the condition. As there is evidence to suggest epigenetics has a role in chronic pain (Uchida *et al.*, 2010; Vossen *et al.*, 2010; Aggarwal, 2004; de Andrade *et al.*, 2017; Denk and McMahon, 2012), and as there is an association between epigenetics and nutritional imbalances (González-Recio *et al.*, 2012; Carey, 2011), it has potential to offer important insight into the development of chronic lameness. Research linking epigenetics and lameness should be conducted alongside the development of the scoring system, to better direct what variables should be included. This project has already highlighted the importance in taking into consideration multiple different fields of research, epigenetics therefore, should not be discounted from the discussion.

4.3.2. Treatment

The standard practice of treating lame cases has been discussed in Section 1.4.2. However, there are still issues with how to treat moderately lame individuals. Garcia-Munoz et al. (2017) found that the use of hoof treatment on mildly lame individuals caused no improvement in their condition. If the method proposed in this project was developed further, or if electronic sensors became more reliable, the industry would need a method to effectively treat those mildly lame cases.

While alternative management practices could be implemented, such as moving susceptible cows closer to the milking parlour or housing individuals on a softer material than concrete (Garcia-Munoz *et al.*, 2017), these practices may miss the internal cause. The potential influence of epigenetics on lameness could provide a potential solution and present an effective treatment plan.

As epigenetic modifications bear no influence on the genetic sequence of the individual there is the potential their effects can be reversed (Triantaphyllopoulos et al., 2016). The use of enzyme modulators, to regulate gene expression, is a potential therapeutic method known as epigenetic therapy (Selvi *et al.*, 2010). Targeting the molecular causes of epigenetic modifications, with new drug treatments, offers a potential method to either treat or, preferably, prevent several diseases (Gudex *et al.*, 2014). Several animal studies have already shown how pathological changes in the pain epigenome can be reversed through the use of activators and inhibitors of histone modification, and inhibitors of DNA methylation and histone acetylation (Niederberger *et al.*, 2017; Ito *et al.*, 2000). Epigenetic therapy provides a novel method of analgesia, with appropriate modulation of gene expression reducing the nociceptive response (Niederberger *et al.*, 2017), to painful conditions such as lameness.

However, due to the limited research on epigenetic modifications and disease in livestock (Ibeagha-Awemu and Zhao, 2015), the current treatment methods lack specificity and accurate delivery to target tissues (Niederberger *et al.*, 2017). Further research is therefore necessary to mitigate the negative influences of intensive farming on animal welfare.

4.4. The future of dairy farming

The discussion of epigenetics and how to improve lameness identification however, will be rendered redundant if we fail to consider the future of the dairy industry. While over the past 70 years we have seen steady increases in efficiency; with genetic selection, increased management efforts, and improvements in nutrition enabling dairy cows to express higher milk yields; this increase will not be able to continue forever (Bradford *et al.*, 2016; VandeHaar *et al.*, 2016). The trajectory the dairy cow is currently on is not sustainable, soon her genetic potential to produce milk will be reached as there is a trade-off between the amount of food ingested, and the time it takes to get processed by the gastrointestinal tract (Bradford *et al.*, 2016). Although emphasis can be placed on improving metabolic and digestive efficiency, to increase the proportion of feed allocated toward milk production and away from growth and maintenance (VandeHaar *et al.*, 2016); moving forward, a greater emphasis should be placed on other inefficiencies in the system in order to improve the use of resources by our livestock (Bradford *et al.*, 2016).

The use of resources by the dairy industry is not only important economically, but also ecologically as concerns about the impact of agriculture on the environment increase (Kock *et al.*, 2018; Connor, 2015; Zhang *et al.*, 2017). Of the total anthropogenic greenhouse gas (GHG) emissions, 14.5% comes from the livestock sector, with 20% of that figure accounted for by milk production (Gerber, 2013). More recent statistics state, in 2015, of the total GHG emitted in the United States, 8% came from the agricultural sector (US Environmental Protection Agency, 2017), and in the UK in 2016, the agriculture sector accounted for 10% of the total GHG emitted (UK Department for Business, 2018). The main sources of emissions, representing 45 and 39% of total sector emissions respectively, are enteric fermentation from ruminants, and feed production and processing; with manure storage and processing accounting for a further 10% (Gerber, 2013). As methane has a global warming potential 25 times greater than carbon dioxide, and as a large portion of the 37% of anthropogenic methane released by the livestock sector comes from the enteric fermentation of ruminants, it is an issue of great concern within the dairy industry (de Haas *et al.*, 2017; Steinfeld *et al.*, 2006).

In line with increasing evidence of the negative influence anthropogenic activities have on the environment, there is a global drive to reduce emissions wherever possible. In the UK, the fifth carbon budget sets out to reduce GHG emissions by 57% (relative to 1990) by 2030, with a target of reducing emissions from the agricultural sector by 15% (Committee on Climate Change, 2018). According to the

Committee on Climate Change (2018) a decrease in emissions, by 18%, has already been reported between 1990 and 2008.

While reductions in emissions have been documented, the necessity of sustainable agriculture only continues to increase, as the world's growing population results in increasing demand (Beddington, 2011). As globalisation continues to intensify, a Foresight report states five key challenges we will face in the future (Beddington, 2011):

1. Sustainably meeting the demands of a growing population, ensuring the affordability of food supplies.
2. Safeguarding the most vulnerable from any potential instability in food supplies, ensuring there are adequate supplies for those in need.
3. Ending the global issue of hunger by ensuring food security for all.
4. Balancing the global demand for food with the impact food systems have on the climate.
5. Preserving global land surfaces and water bodies to maintain ecosystem services and biodiversity.

These five challenges are important in highlighting to policy makers how we must consider the future when approaching the issue of food security today. Sustainable agriculture exists to meet the needs of the present without negatively impacting the ability for the needs of the future to be met (Farm Animal Welfare Committee, 2017). The goal of sustainable agriculture is to promote animal and producer wellbeing, without negatively impacting the environment (Connor, 2015). As available land is scarce, the concept of sustainable intensification is becoming a new priority, as this acts to simultaneously increase the efficiency at which inputs are used and yields are gained, whilst reducing any negative effects of food production on the environment (Beddington, 2011).

Efficiency appears to be the key to the future. Addressing the inefficiency of input use is a fundamental way we can achieve sustainable intensification, as improvements in the effective use of natural resources show a negative correlation to the amount of GHG emitted (Gerber, 2013). Although the UK already expends effort to improve dairy farm efficiency, and to keep emission intensities relatively low, the volume of production remains high (Gerber, 2013). Therefore, any small action to improve certain farm operations such as, feed production, manure management and energy use, will cumulatively result in large emission reductions (Gerber, 2013). Two main ways sustainable intensification can be improved in dairy production involve improving nutrition and metabolic efficiency (Zhang *et al.*, 2017; Gerber, 2013), and reproductive performance, so fewer replacement cows need to be fed and managed (Adler *et al.*, 2013; Gerber, 2013).

Both of these solutions can be achieved through genetic selection. For example, to address the issue of nutrition and metabolic efficiency, one can genetically select for greater feed efficiency, by lowering residual feed intake (RFI) (Connor, 2015). RFI is a method of measuring net feed efficiency by calculating the difference between a cow's actual energy intake and her predicted energy intake (Connor, 2015). The aim of selection based on RFI, is for animals that have a lower dry matter intake (DMI), a greater feed conversion ratio and a reduced amount of enteric methane emissions (Basarab *et al.*, 2013). In terms of digestion, research could also identify the genes associated with increased methane emissions, so they can be avoided in future selection efforts (de Haas *et al.*, 2017).

It seems, to move forward, the future of animal welfare relies on sustainable farming practices, predominantly achieved through genetic selection. In relation to the dairy cow, these selection efforts need to deviate away from increasing the milk yield of that individual, and towards improving the efficiency at which that individual utilises available resources. Due to increasing population sizes causing an increase in demand, it is imprudent to suggest that farming should, and could, return to multiple smallholders. Intensive dairy farming does seem to be the future, but that does not mean it has to be at the complete expense of the cow. With a greater understanding of lameness risk factors, epigenetic influences and the complexity of genetic selection, there is no reason why the welfare of the dairy cow can't be improved, and production levels maintained.

Using this project's proposed diagnostic tool, improved monitoring of dairy cows is possible. With the improvement of data collection, farmers can identify the point at which the cow is at risk of developing lameness and treat the case accordingly. The premise of the scoring system is not limited to lameness, with multivariate analysis offering a solution to other welfare issues such as mastitis. To make sure efficiency does not come at the cost of animal welfare, farmers must routinely keep a record of their cow's health so any changes are identified and treated as soon as possible. By regularly monitoring cows, they will not only be able to promptly treat new cases, they will also be able to track those susceptible to a reoccurring condition. Regular data collection will minimise the prevalence of chronic lameness as the cows at risk will be identified and treated before the condition has the opportunity to develop further.

4.5. The impact of Brexit on animal welfare and lameness research

One potential limiting factor to the development and implementation of the method discussed here is the impact of Brexit. Since the UK joined the European Union, it has been supported in its efforts to improve animal welfare, with an average €70 million dedicated to animal welfare causes each year, with 71% of this fund given to the farmers, in the form of animal welfare payments (European Commission, 2012).

These payments predominantly stem from Common Agricultural Policy (CAP) (European Commission, 2018b), which functions to support and engender competitiveness and sustainability of agriculture among the EU's 28 member states (European Commission, 2018a). Through direct payments, the CAP mitigates potential market volatility and stabilises farm revenues (European Commission, 2018a). The EU will invest nearly €28 billion in the UK's rural areas and farming sector, between 2014 and 2020, making the UK one of the largest recipients of direct payments (European Commission, 2018a). Due to Russia's ban on agricultural imports from the EU in 2014 (European Commission, 2015b), the support of these direct payments was, and continues to be, a key safety net to UK farmers, particularly to those in the dairy industry (European Commission, 2018a). Unfortunately for the Remain campaign, only 57% of the British population were aware of the CAP, and the support it offered farmers (European Commission, 2015a).

While Brexit leaves animal welfare in a vulnerable position, as over 40 animal welfare laws stem from EU law, with 17 laws relating to farm animals (RSPCA, 2018), there is an opportunity for improvement (Committee on Climate Change, 2018). As UK farmers pride themselves in high farm animal welfare standards, there is a consensus of maintaining this commitment post-Brexit (UK Parliament, 2017). The UK have the ability to choose which EU laws will be mirrored in our domestic legislation and have the opportunity to improve upon EU policy by linking more directly actions that would result in greater farmer support and lower GHG emissions (Committee on Climate Change, 2018). However, the UK must consider trading relations with nations who don't share the EU's high welfare standards (UK Parliament, 2017; RSPCA, 2018) as not every nation shares the EU's hope for global recognition of animal welfare and shared responsibility to maintain fair competitiveness between producers (European Commission, 2012). Therefore, should the UK decide to trade with nations that have lower animal welfare standards, such as the US (RSPCA, 2018), they may risk undermining the high standards they are known for and may subsequently impact future trade relations (UK Parliament, 2017).

Furthermore, should the UK lower their welfare standards with cheap imports, farmers may feel demotivated to improve to livestock welfare, and reduce lameness prevalence. As their income is threatened by prices governed by the level of international trade, parliamentary decisions post-Brexit may undo the progress so far made in the industry. While primary motivating factors for farmers are their pride in their herd and feeling sorry for lame cows, cost still has a decisive influence in farmer behaviour (Leach *et al.*, 2010b). If their financial security is reduced further, the cost of lameness treatment and prevention could be seen to alter the opinions of the farmer.

It is apparent the government have many decisions to make as the UK transitions to leave the EU. As the livestock industry increasingly acknowledges the needs of animals, to experience both positive and negative emotions, the issue of Brexit should not be allowed to be a threat to further progress. The decision this project is most in agreement with, comes from a recent parliamentary report that states "scientific evidence and advice should be at the heart of any farm animal welfare policy decisions" (UK Parliament, 2017). By continuing to support scientific research into the study of animal welfare, the government will have greater evidence as to why this aspect of farming should be safeguarded in future policy decisions. Without the support of the government, an important stakeholder in the agricultural industry, the implementation of innovations, such as the diagnostic tool proposed in this project, will be threatened. It is important that projects such as the AHDB Dairy Healthy Feet Programme use their position to voice their concerns during this period of transition (AHDB Dairy, 2017).

5. Conclusion

The concept of animal welfare has evolved extensively since Broom defined it in 1986. However, with Brexit in motion and other nations still lagging behind the UK in terms of societal recognition and policy decisions (RSPCA, 2018; European Commission, 2015a), there is still a long way to go before real progress is made. Public awareness is key in driving change, therefore greater clarity and communication is needed to ensure the general population are aware of how animals are treated in their country.

The issue of lameness in dairy cattle is one aspect of animal welfare that deserves greater recognition. Based on the percentage prevalence of lameness, both in the UK and worldwide, it is highly probable that the milk we consume has come from a lame cow; from an individual who is experiencing pain. As our understanding of pain and the sentience of animals' increases, ethically speaking this is an issue we can no longer ignore.

With improvements in technology, and the efficient use of available data, this project shows how multivariate analysis could be a possible solution in identifying lame individuals. The method used in this study mirrors techniques used in human medicine and has far reaching applications in both lameness identification and other animal welfare issues. The benefits of using multiple data sources are numerous, and positive progress has already been noted (see Section 1.5). This project highlights how the same advancements can be made in veterinary medicine, as positive results were gained from this initial study.

By consulting the experts, this project also identified a large gap in the industry's understanding of chronic lameness and highlighted the necessity for more research to determine a universal definition. Chronic lameness needs to be brought into discussion, particularly as the issue causes long-term suffering, and experts need to agree upon how it can be identified.

With further development, and the incorporation of the experts' opinion, the potential for success will only increase. By conducting both a social science study alongside the development of an analytical technique, this project aimed to ensure this method was able to walk before it could run. The results from both studies when used in conjunction, will provide more grounded support for future development.

While this project shows how lameness prevalence can be reduced, the ultimate goal is to remove the issue altogether. The understanding and inclusion of genetic heritability factors is increasingly used in medicine, and is a potential way in which this scoring method could be taken forward. An understanding of epigenetics, paired with the use of multivariate analysis, could vindicate the damage caused by our intensive farming practices. By studying the links between epigenetics and disease, scientists could potentially reprogram the dairy cow's evolutionary trajectory. They could rewrite the rules and remove lameness altogether, so it no longer impacts the welfare of our dairy cattle. Epigenetics could be the antithesis of many animal welfare conditions and should be considered more seriously in future research endeavours. The industry should strive towards identifying epigenetic modifications, which could be at the root of lameness and chronic pain, to add the heritability of the condition to our arsenal of measurements.

This project has highlighted the many interlinking causes and risk factors of lameness and how its identification and treatment can prove very complex. The study of veterinary science should not be allowed to stagnate. It is important to ensure veterinary medicine is not primitive in its approach to technological advances. There are many similarities between the study of human and animal anatomy, therefore collaboration should be considered to ensure progress in both fields. This project has successfully added value to the potential of multivariate analysis in veterinary medicine, specifically lameness, and has provided a stepping stone between the current mobility score and future technological solutions.

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Appendix 1

Risk Factor	Association with lameness	Evidence
Age and Parturition	• Stress • Difficulty acclimating to environmental changes • Risk of other diseases • Hormonal changes • Body condition	(Bergsten and Frank, 1996) (Vermunt and Greenough, 1995) (Alban *et al.*, 1995) (Leach *et al.*, 1997) (Raber *et al.*, 2004)
Environment	• Cleanliness of floors • Types of floor surfaces • Type of housing • Bedding material	(Bergsten and Pettersson, 1992) (Barker *et al.*, 2010) (Wierenga and Peterse, 1987) (Somers *et al.*, 2003) (Cramer *et al.*, 2008)
Nutritional and feeding management	• Acidosis • Transition period • Protein • Biotin	(Bicalho and Oikonomou, 2013) (Lean *et al.*, 2013) (Bramley *et al.*, 2008) (Danscher *et al.*, 2009) (Livesey and Fleming, 1984) (Manson and Leaver, 1988b) (Fitzgerald *et al.*, 2000)

Appendix 2

	Score	Description
Severe underconditioning	1.00	Spinous process is prominent and horizontal processes are shap. At the tail head there is no fatty tissue under the skin and a deep cavity is visible.
	1.25	
	1.50	
	1.75	
Frame obvious	2.00	The horizontal processes can be individually identified with rounded ends. At the tail head the pin bones are prominent but there is some fat under the skin and a shallow cavity is visible.
	2.25	
	2.50	
	2.75	
Frame and covering well balanced	3.00	At the tail head there is fat covering the whole area and the skin is smooth. Around the loin the end of the horizontal process can be felt, and a slight depression is visible.
	3.25	
	3.50	
	3.75	
Frame not as visible as covering	4.0	Around the loin the horizontal processes cannot be felt and have a completely rounded appearance. No cavity is visible, all space is filled, and areas of fat are evident.
	4.25	
	4.50	
	4.75	
Severe overconditioning	5.0	Tail head is buried in fatty tissue and the pelvis is no longer palpable, even with firm pressure.

Appendix 3

```
% cowscript_v6
% author: Charlie Bunce & Beth Hewitt
% matlab R2015b

%% read in data and process for visualisation

MobilityScore_data = xlsread('JW_19_3_18.xlsx', 'Mobility_Mar_19_18');
MilkYield_data = xlsread('JW_19_3_18.xlsx', 'Milk_Yield_Mar_19_18');
Cell_data = xlsread('JW_19_3_18.xlsx', 'SCC_Mar_19_18');
BodyCon_data = xlsread('JW_19_3_18.xlsx', 'BCS_Mar_19_18');
Lactation_data = xlsread('JW_19_3_18.xlsx', 'Lactation_Mar_19_18');

MobilityScore = MobilityScore_data(:,2) ;
MilkYield = MilkYield_data(:,2);
Cell = Cell_data(:,2) ;
BodyCon = BodyCon_data(:,2) ;
Lactation = Lactation_data(:,2) ;

figure ;
subplot(2,2,1) ;
hist(MobilityScore) ;
title('Mobility Score') ;
subplot(2,2,2) ;
hist(MilkYield) ;
title('Milk Yield') ;
subplot(2,2,3) ;
hist(Cell) ;
title('Somatic Cell Count') ;
subplot(2,2,4) ;
hist(BodyCon) ;
title('Body Condition Score') ;
hist(Lactation) ;
title('Lactation') ;

a = input('Give selected cow row:', 's');
cow_input = str2num(a);

Z_MobilityScore = zscore(MobilityScore) ;
Z_MilkYield = zscore(MilkYield) ;
Z_Cell = zscore(Cell) ;
Z_BodyCon = zscore(BodyCon) ;
Z_Lactation = zscore(Lactation) ;

figure ;
subplot(3,2,1) ;
hist(Z_MobilityScore) ;
title('MobilityScore') ;
subplot(3,2,2) ;
hist(Z_MilkYield) ;
title('Milk Yield Score') ;
subplot(3,2,3) ;
hist(Z_Cell) ;
title('Somatic Cell Count') ;
subplot(3,2,4) ;
hist(Z_BodyCon) ;
title('Body Condition Score') ;
subplot(3,2,5) ;
```

```matlab
hist(Z_Lactation) ;
title('Lactation number') ;

%% run basic analysis

Mob_op1 = range((Z_MobilityScore)/4) ;
Mob_op2 = (Mob_op1*2) ;
Mob_op3 = (Mob_op1*3) ;
Mob_op4 = (Mob_op1*4) ;

for ni = 1:length(Z_MobilityScore)
    if Z_MobilityScore(ni,:) < Mob_op1
        lamescore_data(ni,1) = 0 ;
    else
        if Z_MobilityScore(ni,:) <Mob_op2 & Z_MobilityScore(ni,:) > Mob_op1
        lamescore_data(ni,1) = 1 ;
        else
            if Z_MobilityScore(ni,:) < Mob_op3 & Z_MobilityScore(ni,:) >
Mob_op2
            lamescore_data(ni,1) = 2 ;
            else
                if Z_MobilityScore(ni,:) < Mob_op4 & Z_MobilityScore(ni,:)
> Mob_op3
                    lamescore_data(ni,1) = 3 ;
                end
            end
        end
    end
end

Milk_op1 = range((Z_MilkYield)/4) ;
Milk_op2 = (Milk_op1*2) ;
Milk_op3 = (Milk_op1*3) ;
Milk_op4 = (Milk_op1*4) ;

for ni = 1:length(Z_MilkYield)
    if Z_MilkYield(ni,:) < Milk_op1
        lamescore_data(ni,2) = 3 ;
    else
        if Z_MilkYield(ni,:) < Milk_op2 & Z_MilkYield(ni,:) > Milk_op1
        lamescore_data(ni,2) = 2 ;
        else
            if Z_MilkYield(ni,:) < Milk_op3 & Z_MilkYield(ni,:) > Milk_op2
            lamescore_data(ni,2) = 1 ;
            else
                if Z_MilkYield(ni,:) < Milk_op4 & Z_MilkYield(ni,:) >
Milk_op3
                    lamescore_data(ni,2) = 0 ;
                end
            end
        end
    end
end

Cell_op1 = range((Z_Cell)/4) ;
Cell_op2 = (Cell_op1*2) ;
Cell_op3 = (Cell_op1*3) ;
Cell_op4 = (Cell_op1*4) ;

for ni = 1:length(Z_Cell)
```

```
    if Z_Cell(ni,:) < Cell_op1
        lamescore_data(ni,3) = 0 ;
    else
        if Z_Cell(ni,:) < Cell_op2 & Z_Cell(ni,:) > Cell_op1
        lamescore_data(ni,3) = 1 ;
        else
            if Z_Cell(ni,:) < Cell_op3 & Z_Cell(ni,:) > Cell_op2
            lamescore_data(ni,3) = 2 ;
            else
                if Z_Cell(ni,:) < Cell_op4 & Z_Cell(ni,:) > Cell_op3
                    lamescore_data(ni,3) = 3 ;
                end
            end
        end
    end
end

Body_op1 = range((Z_BodyCon)/4);
Body_op2 = (Body_op1*2);
Body_op3 = (Body_op1*3);
Body_op4 = (Body_op1*4);

for ni = 1:length(Z_BodyCon)
    if Z_BodyCon(ni,:) < Body_op1
        lamescore_data(ni,4) = 3 ;
    else
        if Z_BodyCon(ni,:) < Body_op2 & Z_BodyCon(ni,:) > Body_op1
        lamescore_data(ni,4) = 2 ;
        else
            if Z_BodyCon(ni,:) < Body_op3 & Z_BodyCon(ni,:) > Body_op2
            lamescore_data(ni,4) = 1 ;
            else
                if Z_BodyCon(ni,:) < Body_op4 & Z_BodyCon(ni,:) > Body_op3
                    lamescore_data(ni,4) = 0 ;
                end
            end
        end
    end
end

Lac_op1 = range((Z_Lactation)/4);
Lac_op2 = (Lac_op1*2);
Lac_op3 = (Lac_op1*3);
Lac_op4 = (Lac_op1*4);

for ni = 1:length(Z_Lactation)
    if Z_Lactation(ni,:) < Lac_op1
        lamescore_data(ni,5) = 0 ;
    else
        if Z_Lactation(ni,:) < Lac_op2 & Z_Lactation(ni,:) > Lac_op1
        lamescore_data(ni,5) = 1 ;
        else
            if Z_Lactation(ni,:) < Lac_op3 & Z_Lactation(ni,:) > Lac_op2
            lamescore_data(ni,5) = 2 ;
            else
                if Z_Lactation(ni,:) < Lac_op4 & Z_Lactation(ni,:) >
Lac_op3
                    lamescore_data(ni,5) = 3 ;
                end
            end
```

```
        end
    end
end

for ni = 1:length(lamescore_data)
lame_score(ni,:) = sum(lamescore_data(ni,:));
end

y1 = 0 ;
y2 = 300 ;

x = lame_score(cow_input,:);

figure ;
hist(lame_score);
set(gca, 'XLim', [0 20])
hold on
line([x x], [y1 y2]);
title('Lame score frequency') ;
xlabel('Lame score') ;
ylabel('Number of cows')
dim = [.2 .5 .3 .3];
str = 'Specified Cow';
annotation('textbox',dim,'String',str,'FitBoxToText','on');
```

Appendix 4

```
% cowscript_v6
% author: Charlie Bunce & Beth Hewitt
% matlab R2015b

%% read in data and process for visualisation

MobilityScore_data = xlsread('JW_19_3_18.xlsx', 'Mobility_Mar_19_18');
Cell_data = xlsread('JW_19_3_18.xlsx', 'SCC_Mar_19_18');
BodyCon_data = xlsread('JW_19_3_18.xlsx', 'BCS_Mar_19_18');
Lactation_data = xlsread('JW_19_3_18.xlsx', 'Lactation_Mar_19_18');

MobilityScore = MobilityScore_data(:,2) ;
Cell = Cell_data(:,2) ;
BodyCon = BodyCon_data(:,2) ;
Lactation = Lactation_data(:,2) ;

figure ;
subplot(2,2,1) ;
hist(MobilityScore) ;
title('Mobility Score') ;
subplot(2,2,2) ;
hist(Cell) ;
title('Somatic Cell Count') ;
subplot(2,2,3) ;
hist(BodyCon) ;
title('Body Condition Score') ;
subplot(2,2,4) ;
hist(Lactation) ;
title('Lactation') ;

a = input('Give selected cow row:', 's');
cow_input = str2num(a);

Z_MobilityScore = zscore(MobilityScore) ;
Z_Cell = zscore(Cell) ;
Z_BodyCon = zscore(BodyCon) ;
Z_Lactation = zscore(Lactation) ;

figure ;
subplot(2,2,1) ;
hist(Z_MobilityScore) ;
title('MobilityScore') ;
subplot(2,2,2) ;
hist(Z_Cell) ;
title('Somatic Cell Count') ;
subplot(2,2,3) ;
hist(Z_BodyCon) ;
title('Body Condition Score') ;
subplot(2,2,4) ;
hist(Z_Lactation) ;
title('Lactation number') ;

%% run basic analysis

Mob_op1 = range((Z_MobilityScore)/4) ;
Mob_op2 = (Mob_op1*2) ;
Mob_op3 = (Mob_op1*3) ;
```

```
Mob_op4 = (Mob_op1*4) ;

for ni = 1:length(Z_MobilityScore)
    if Z_MobilityScore(ni,:) < Mob_op1
        lamescore_data(ni,1) = 0 ;
    else
        if Z_MobilityScore(ni,:) <Mob_op2 & Z_MobilityScore(ni,:) > Mob_op1
        lamescore_data(ni,1) = 1 ;
        else
            if Z_MobilityScore(ni,:) < Mob_op3 & Z_MobilityScore(ni,:) >
Mob_op2
            lamescore_data(ni,1) = 2 ;
            else
                if Z_MobilityScore(ni,:) < Mob_op4 & Z_MobilityScore(ni,:)
> Mob_op3
                    lamescore_data(ni,1) = 3 ;
                end
            end
        end
    end
end


Cell_op1 = range((Z_Cell)/4) ;
Cell_op2 = (Cell_op1*2) ;
Cell_op3 = (Cell_op1*3) ;
Cell_op4 = (Cell_op1*4) ;

for ni = 1:length(Z_Cell)
    if Z_Cell(ni,:) < Cell_op1
        lamescore_data(ni,3) = 0 ;
    else
        if Z_Cell(ni,:) < Cell_op2 & Z_Cell(ni,:) > Cell_op1
        lamescore_data(ni,3) = 1 ;
        else
            if Z_Cell(ni,:) < Cell_op3 & Z_Cell(ni,:) > Cell_op2
            lamescore_data(ni,3) = 2 ;
            else
                if Z_Cell(ni,:) < Cell_op4 & Z_Cell(ni,:) > Cell_op3
                    lamescore_data(ni,3) = 3 ;
                end
            end
        end
    end
end

Body_op1 = range((Z_BodyCon)/4);
Body_op2 = (Body_op1*2);
Body_op3 = (Body_op1*3);
Body_op4 = (Body_op1*4);

for ni = 1:length(Z_BodyCon)
    if Z_BodyCon(ni,:) < Body_op1
        lamescore_data(ni,4) = 3 ;
    else
        if Z_BodyCon(ni,:) < Body_op2 & Z_BodyCon(ni,:) > Body_op1
        lamescore_data(ni,4) = 2 ;
        else
            if Z_BodyCon(ni,:) < Body_op3 & Z_BodyCon(ni,:) > Body_op2
            lamescore_data(ni,4) = 1 ;
```

```
            else
                if Z_BodyCon(ni,:) < Body_op4 & Z_BodyCon(ni,:) > Body_op3
                    lamescore_data(ni,4) = 0 ;
                end
            end
        end
    end
end

Lac_op1 = range((Z_Lactation)/4);
Lac_op2 = (Lac_op1*2);
Lac_op3 = (Lac_op1*3);
Lac_op4 = (Lac_op1*4);

for ni = 1:length(Z_Lactation)
    if Z_Lactation(ni,:) < Lac_op1
        lamescore_data(ni,5) = 0 ;
    else
        if Z_Lactation(ni,:) < Lac_op2 & Z_Lactation(ni,:) > Lac_op1
        lamescore_data(ni,5) = 1 ;
        else
            if Z_Lactation(ni,:) < Lac_op3 & Z_Lactation(ni,:) > Lac_op2
            lamescore_data(ni,5) = 2 ;
            else
                if Z_Lactation(ni,:) < Lac_op4 & Z_Lactation(ni,:) >
Lac_op3
                    lamescore_data(ni,5) = 3 ;
                end
            end
        end
    end
end

for ni = 1:length(lamescore_data)
lame_score(ni,:) = sum(lamescore_data(ni,:));
end

y1 = 0 ;
y2 = 300 ;

x = lame_score(cow_input,:);

figure ;
hist(lame_score);
set(gca, 'XLim', [0 20])
hold on
line([x x], [y1 y2]);
title('Lame score frequency') ;
xlabel('Lame score') ;
ylabel('Number of cows')
dim = [.2 .5 .3 .3];
str = 'Specified Cow';
annotation('textbox',dim,'String',str,'FitBoxToText','on');
```

Appendix 5

```
% cowscript_v6
% author: Charlie Bunce & Beth Hewitt
% matlab R2015b

%% read in data and process for visualisation

MilkYield_data = xlsread('JW_19_3_18.xlsx', 'Milk_Yield_Mar_19_18');
Cell_data = xlsread('JW_19_3_18.xlsx', 'SCC_Mar_19_18');
BodyCon_data = xlsread('JW_19_3_18.xlsx', 'BCS_Mar_19_18');
Lactation_data = xlsread('JW_19_3_18.xlsx', 'Lactation_Mar_19_18');

MilkYield = MilkYield_data(:,2) ;
Cell = Cell_data(:,2) ;
BodyCon = BodyCon_data(:,2) ;
Lactation = Lactation_data(:,2) ;

figure ;
subplot(2,2,1) ;
hist(MilkYield) ;
title('Milk Yield') ;
subplot(2,2,2) ;
hist(Cell) ;
title('Somatic Cell Count') ;
subplot(2,2,3) ;
hist(BodyCon) ;
title('Body Condition Score') ;
subplot(2,2,4) ;
hist(Lactation) ;
title('Lactation') ;

a = input('Give selected cow row:', 's');
cow_input = str2num(a);

Z_MilkYield = zscore(MilkYield) ;
Z_Cell = zscore(Cell) ;
Z_BodyCon = zscore(BodyCon) ;
Z_Lactation = zscore(Lactation) ;

figure ;
subplot(2,2,1) ;
hist(Z_MilkYield) ;
title('Milk Yield') ;
subplot(2,2,2) ;
hist(Z_Cell) ;
title('Somatic Cell Count') ;
subplot(2,2,3) ;
hist(Z_BodyCon) ;
title('Body Condition Score') ;
subplot(2,2,4) ;
hist(Z_Lactation) ;
title('Lactation number') ;

%% run basic analysis

Milk_op1 = range((Z_MilkYield)/4) ;
Milk_op2 = (Milk_op1*2) ;
```

```
Milk_op3 = (Milk_op1*3) ;
Milk_op4 = (Milk_op1*4) ;

for ni = 1:length(Z_MilkYield)
    if Z_MilkYield(ni,:) < Milk_op1
          lamescore_data(ni,2) = 3 ;
    else
        if Z_MilkYield(ni,:) < Milk_op2 & Z_MilkYield(ni,:) > Milk_op1
        lamescore_data(ni,2) = 2 ;
        else
            if Z_MilkYield(ni,:) < Milk_op3 & Z_MilkYield(ni,:) > Milk_op2
            lamescore_data(ni,2) = 1 ;
            else
                if Z_MilkYield(ni,:) < Milk_op4 & Z_MilkYield(ni,:) >
Milk_op3
                    lamescore_data(ni,2) = 0 ;
                end
            end
        end
    end
end


Cell_op1 = range((Z_Cell)/4) ;
Cell_op2 = (Cell_op1*2) ;
Cell_op3 = (Cell_op1*3) ;
Cell_op4 = (Cell_op1*4) ;

for ni = 1:length(Z_Cell)
    if Z_Cell(ni,:) < Cell_op1
        lamescore_data(ni,3) = 0 ;
    else
        if Z_Cell(ni,:) < Cell_op2 & Z_Cell(ni,:) > Cell_op1
        lamescore_data(ni,3) = 1 ;
        else
            if Z_Cell(ni,:) < Cell_op3 & Z_Cell(ni,:) > Cell_op2
            lamescore_data(ni,3) = 2 ;
            else
                if Z_Cell(ni,:) < Cell_op4 & Z_Cell(ni,:) > Cell_op3
                    lamescore_data(ni,3) = 3 ;
                end
            end
        end
    end
end

Body_op1 = range((Z_BodyCon)/4);
Body_op2 = (Body_op1*2);
Body_op3 = (Body_op1*3);
Body_op4 = (Body_op1*4);

for ni = 1:length(Z_BodyCon)
    if Z_BodyCon(ni,:) < Body_op1
        lamescore_data(ni,4) = 3 ;
    else
        if Z_BodyCon(ni,:) < Body_op2 & Z_BodyCon(ni,:) > Body_op1
        lamescore_data(ni,4) = 2 ;
        else
            if Z_BodyCon(ni,:) < Body_op3 & Z_BodyCon(ni,:) > Body_op2
            lamescore_data(ni,4) = 1 ;
```

```
            else
                if Z_BodyCon(ni,:) < Body_op4 & Z_BodyCon(ni,:) > Body_op3
                    lamescore_data(ni,4) = 0 ;
                end
            end
        end
    end
end

Lac_op1 = range((Z_Lactation)/4);
Lac_op2 = (Lac_op1*2);
Lac_op3 = (Lac_op1*3);
Lac_op4 = (Lac_op1*4);

for ni = 1:length(Z_Lactation)
    if Z_Lactation(ni,:) < Lac_op1
        lamescore_data(ni,5) = 0 ;
    else
        if Z_Lactation(ni,:) < Lac_op2 & Z_Lactation(ni,:) > Lac_op1
        lamescore_data(ni,5) = 1 ;
        else
            if Z_Lactation(ni,:) < Lac_op3 & Z_Lactation(ni,:) > Lac_op2
            lamescore_data(ni,5) = 2 ;
            else
                if Z_Lactation(ni,:) < Lac_op4 & Z_Lactation(ni,:) >
Lac_op3
                    lamescore_data(ni,5) = 3 ;
                end
            end
        end
    end
end

for ni = 1:length(lamescore_data)
lame_score(ni,:) = sum(lamescore_data(ni,:));
end

y1 = 0 ;
y2 = 300 ;

x = lame_score(cow_input,:);

figure ;
hist(lame_score);
set(gca, 'XLim', [0 20])
hold on
line([x x], [y1 y2]);
title('Lame score frequency') ;
xlabel('Lame score') ;
ylabel('Number of cows')
dim = [.2 .5 .3 .3];
str = 'Specified Cow';
annotation('textbox',dim,'String',str,'FitBoxToText','on');
```

Appendix 6

Table 1: The descriptive statistics for Herd 1 for the 08.01.18. At this particular time point, the mean lameness score was 6 and the mean mobility score was 1. The percentage of lame cows (cows scoring 2 or 3 using the mobility score) was 21.3%.

08.01.18

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	366	.5	61.2	35.988	10.8106
SCC	366	0	2396	127.25	255.398
Lactation	366	1	7	2.33	1.305
BCS	366	2.0	4.0	3.037	.4113
Mobility	366	0	3	.92	.715
Lameness	366	5	13	6.33	.881
% of lame cows					**21.3**

Table 2: The descriptive statistics for Herd 1 for the 22.01.18. The mean mobility score for this time point was 1 and the mean lameness score was 6. The percentage of lame cows (cows scored as 2 or 3 using the mobility score) was 24.5%.

22.01.18

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	343	.0	62.0	36.991	11.0919
SCC	343	0	2396	125.37	255.114
Lactation	343	1	7	2.31	1.286
BCS	343	2.0	4.5	2.937	.4356
Mobility	343	0	3	.98	.733
Lameness	343	5	12	6.38	.860
% of lame cows					**24.5**

Table 3: The descriptive statistics for Herd 1 for the 05.02.18. The table shows a mean lameness score of 6 and a mean mobility score of 1. The percentage of lame cows (cows that scored 2 or 3 using the mobility score) was 23.7%.

05.02.18

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	430	4.7	60.3	36.045	10.4963
SCC	430	0	8955	177.31	641.635
Lactation	430	1	7	2.30	1.314
BCS	430	2.0	4.5	3.074	.5101
Mobility	430	0	3	1.00	.711
Lameness	430	4	10	6.24	.867
% of lame cows					**23.7**

Table 3: The descriptive statistics for Herd 1 for the 19.02.18. For this time point, the mean mobility score was 1 and the mean lameness score was 6. The percentage of lame cows (cows that scored 2 or 3 using the mobility score) was 22.9%.

<u>19.02.18</u>

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	371	.0	60.6	33.927	10.2374
SCC	371	0	8955	185.79	685.055
Lactation	371	1	7	2.30	1.339
BCS	371	.5	4.5	2.927	.5071
Mobility	371	0	3	1.05	.650
Lameness	371	5	10	6.33	.822
% of lame cows					**22.9**

Table 4: The descriptive statistics for Herd 1 for the 05.03.18. This table shows a mean lameness score of 6 and a mean mobility score of 1. The percentage of lame cows (cows that scored 2 or 3 using the mobility score) was 28.5%.

<u>05.03.18</u>

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	449	3.2	74.8	37.171	11.3875
SCC	449	0	3825	160.12	365.950
Lactation	449	1	7	2.32	1.318
BCS	449	1.5	4.5	2.909	.4671
Mobility	449	0	3	1.16	.637
Lameness	449	4	10	6.42	.875
% of lame cows					**28.5**

Table 5: The descriptive statistics for Herd 1 for the 19.03.18. This table shows a mean lameness score of 6 and a mean mobility score of 1. The percentage of lame cows (cows that scored 2 or 3 using the mobility score) was 24.3%.

19.03.18

	N	Minimum	Maximum	Mean	Std. Deviation
Milk Yield	366	.5	66.4	34.164	11.1478
SCC	366	0	2588	117.67	254.205
Lactation	366	1	7	2.20	1.227
BCS	366	1.5	4.5	2.910	.4966
Mobility	366	0	3	1.17	.577
Lameness	366	4	10	6.33	.806
% of lame cows					**24.3**

Appendix 7

Table 1: The descriptive statistics for Herd 2 for March 2016. The results show, for March 2016, a mean mobility score of 1 and a mean lameness score of 7. The percentage of lame cows for this particular sample was higher than the national average at 32.3%.

March 2016

	N	Minimum	Maximum	Mean	Std. Deviation
Parity	31	1	6	2.19	1.515
SCC	31	7	1758	189.32	381.998
Milk Yield	31	24.2	51.0	39.581	7.4209
BCS	31	2.0	3.5	2.790	.3360
Mobility	31	1	3	1.42	.672
Lameness	31	5	12	6.84	1.594
% of lame cows					**32.3**

Table 2: The descriptive statistics for Herd 2 for August 2016. The sample used for August 2016 had a mean mobility score of 1 and a mean lameness score of 6. This month showed a very high percentage of lame cows at 44.7%.

August 2016					
	N	Minimum	Maximum	Mean	Std. Deviation
Parity	38	1	6	2.61	1.516
SCC	38	10	687	105.21	155.558
Milk Yield	38	15.1	55.6	37.303	10.6212
BCS	38	2.00	4.00	3.0658	.41380
Mobility	38	0	3	1.45	.602
Lameness	38	4	9	6.26	1.107
% of lame cows					**44.7**

Table 3: The descriptive statistics for Herd 2 for September 2016. In September 2016, the sample of cows used in the analysis had a mean mobility score of 1 and a mean lameness score of 6. The percentage of lame cows was 26.3%.

September 2016					
	N	Minimum	Maximum	Mean	Std. Deviation
Parity	38	1	5	2.11	1.158
SCC	38	5	713	81.92	138.296
Milk Yield	38	13.9	55.4	34.332	9.4136
BCS	38	2.50	3.75	3.1053	.28255
Mobility	38	1	3	1.32	.574
Lameness	38	4	9	6.34	1.192
% of lame cows					**26.3**

Table 4: The descriptive statistics for Herd 2 for November 2016. The mean mobility score for November 2016 and a mean lameness score of 6. There was a very high percentage of lame cows in this sample with a percentage of 48.8%.

November 2016					
	N	Minimum	Maximum	Mean	Std. Deviation
Parity	41	1	6	2.10	1.428
SCC	41	19	566	89.20	94.718
Milk Yield	41	22.4	55.6	38.412	9.4709
BCS	41	2.00	4.00	2.9756	.45002
Mobility	41	0	3	1.56	.838
Lameness	41	3	10	5.98	1.275
% of lame cows					**48.8**

Table 5: The descriptive statistics for Herd 2 for January 2017. In January 2017, the sample used in the analysis had a mean mobility score of 1 and a mean lameness score of 6. The percentage of lame cows for this sample was 39.2%.

January 2017					
	N	Minimum	Maximum	Mean	Std. Deviation
Parity	79	1	7	2.63	1.504
SCC	79	10	1398	112.77	198.829
Milk Yield	79	11.5	60.4	37.653	10.5476
BCS	79	1.5	4.0	2.576	.5316
Mobility	79	0	3	1.19	.907
Lameness	79	5	10	6.48	1.073
% of lame cows					**39.2**

Table 6: The descriptive statistics for Herd for July 2017. The cows used in the analysis from the July 2017 recordings had a mean mobility score of 1 and a mean lameness score of 6. The percentage of lame cows within the sample used was 28.6%.

July 2017					
	N	Minimum	Maximum	Mean	Std. Deviation
Parity	49	1	6	2.57	1.443
SCC	49	6	1076	121.20	217.733
Milk Yield	49	19.4	56.4	35.102	7.6531
BCS	49	1.5	4.0	2.796	.6285
Mobility	49	0	3	1.18	.782
Lameness	49	5	10	6.45	1.174
% of lame cows					**28.6**

Appendix 8

Date: 28/02/2018 (Version 4)

Participant Information Sheet

Study title: Identifying lameness "oddities"- an interview aimed at determining if there are any changes seen in dairy cows, associated with lameness, that have thus far been overlooked.

Invitation paragraph

We would like to invite you to take part in our research study looking at lameness in dairy cows and how diagnosis of the condition can be improved. Before you decide we would like you to understand why the research is being done and what it would involve for you. You may talk to others about the study if you wish. Please ask us if there is anything that is not clear.

What is the purpose of the study?

Currently, there is disagreement among researchers when defining chronic lameness in dairy cows, disagreement which is also reflected in the way the disease is diagnosed (Shearer *et al*., 2012). At present the most commonly used method uses a mobility score to represent the gait of the individual, from lower values representing a healthy gait, to higher values representing a severe limp, and therefore, severe lameness. While the basic premise is widely used, different researchers have adapted the scale to include different definitions and stages. Without a universal method to monitor lameness, one that is sensitive enough to identify mildly and bilaterally lame individuals, it is difficult to map out the progression of the disease and to target treatment when it is most effective. The premise of this project is to develop a scoring system that will combine multiple variables to identify the cows at risk of misdiagnosis. By using multiple aspects of cow behaviour and physiology the developed score will be more equipped at identifying lameness early, allowing early treatment to maximise the recovery of the cow to full health.

In order to maximise the success of the development process, this study is formed of two parts conducted in parallel: the development of the score, and an interview process to determine what is to be used in that score going forward. The first part of the study will use data that is already collected on farm to be used in the development of the code. While this is an important study to evaluate the application of the proposed method, the latter part of the project is key as it involves interviewing 8 experts in the field of lameness, to see if there are any variables currently not measured on farm that may be have been so far overlooked when diagnosing lameness. This study will inform future implementation of the code as it will be better tailored to its purpose. You are invited to participate in a face-to-face or telephone interview, should you be willing. The interview will consist of 3 core questions and should take no longer than 30 minutes. By gaining your expert opinion on what indicators to look for and include in the method, the resulting protocol will be tailored more specifically to its use, and won't be bound by what is already measured on farm.

Why have I been invited?

You have been invited to take part in this study based on your level of experience within the field of lameness. You have been chosen based on your experience in identifying and treating lameness through your role as a veterinarian, or through your contributions to lameness research via your own research endeavours and/or your supervision of others. There will be approximately 8 participants in total, interviewed separately.

Do I have to take part?

Based on the description given about the study and what we are looking to achieve, if you agree to take part, then we will then ask you to sign a consent form. You are free to withdraw at any time, without giving a reason. This will not affect any potential collaboration with our research group in the future.

What will happen to me if I take part and what will I have to do?

As a participant you will be required to answer 3 questions about your experience of lameness and what variables, if any, you think are overlooked when diagnosing the condition. The interview is semi-structured and should take no longer than 30 minutes, depending on the detail you wish to provide when giving your answers.

The interview will be audio recorded, using an encrypted audio recorder, and all responses will be kept anonymous. When the data is analysed using NVivo, names of participants will be removed to ensure anonymity throughout. The media files will be stored on a password protected, University of Bristol secure server and your file will be given an ID number, so no identifying information is used. Your data will be stored until August 2028 when it will be disposed of permanently and securely.

Expenses and payments (only include if applicable)

N/A

What are the possible disadvantages and risks of taking part

We believe there to be no risks or disadvantages of taking part in this study. As mentioned above, anonymity will be maintained throughout the study and should you wish to withdraw for any reason you are allowed to do so.

What are the possible benefits of taking part?

By taking part you are helping research that is aiming to reduce the prevalence of lameness in dairy herds, within the UK. Any positive implementations that result from this study have the potential to improve dairy cow welfare, and in turn farm profitability.

What will happen if I don't want to carry on with the study?

You may withdraw from this study at any time, without giving a reason, by contacting the named researcher. If you decide to withdraw from the study it will not affect subsequent relations with this research group. Any data collected will be disposed of if you decide not to participate.

Will my taking part in this study be kept confidential?

Information will be collected via an encrypted audio recording. All information which is collected about you during the course of the research will be kept strictly confidential, and any information about you will have your name and address removed so that you cannot be recognised.

Only the main researcher will have access to identifiable data. It will be retained until the data analysis has been conducted and disposed of securely, no later than August 2028.

What will happen to the results of the research study?

The results of the study will form a key part of my Masters dissertation. If they are deemed appropriate for publication no identifiable information of participants will be published. If you wish to view the results of the study you may contact us, via the contact details given below, to receive more information either by email or phone.

Who is organising and funding the research?

The research is a self-funded research Masters conducted at the University of Bristol.

Who has reviewed the study?

Health Sciences Faculty Research Ethics Committee (FREC)

Further information and contact details

If you require further information, or have any questions about the study and what is required of you as a participant, don’t hesitate to contact us via email or mobile:

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Appendix 9

Topic guide

University of BRISTOL

Listed below are some potential topics that could be covered during the interview.

- Area of research and experience of lame cows.
- Perceptions of how lame cows are treated and dealt with on farm.
- Lameness indicators that are not recorded as part of the proposed lameness protocol.
- Any necessary steps that should be implemented to reduce lameness.
- The future of lameness, from the way it is defined and diagnosed to the way it could be treated.

Appendix 10

Centre Number:

Study Number:

Patient Identification Number for this trial:

CONSENT FORM

Title of Project: **Development of a multivariate analytical system to identify lameness in dairy cows**

Name of Researcher: **Beth Hewitt**

Please initial all boxes

1. I confirm that I have read and understand the information sheet dated **28/02/2018** (Version 4) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my relationship with the research group or legal rights being affected. ☐

3. I understand my interview and data collected during the study will be kept anonymous. ☐

4. I agree to my interview being audio-recorded. ☐

5. I give my consent for my anonymised data to be publicly available through a repositiory. ☐

6. I agree to take part in the above study. ☐

______________________	______________________	______________________
Name of Participant	Date	Signature
Beth Hewitt ____________	______________________	______________________
Name of Person taking consent.	Date	Signature

Appendix 11

Interview guide

Reiterate to the participant that their responses will be kept anonymous and that should they wish to withdraw at any time they are allowed to do so. Tell them that the interview will be recorded from this point onwards.

From your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

Bearing in mind the information you've been shown and the previous question about lameness indicators- if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure lameness? For example, would you follow the current procedure or would you include other indicators?

Finally, could you give me your definition of chronic lameness?

Potential other questions:

- Do you think there is an issue with the current mobility score used to identify lame cows?
- If you noticed a chronically lame cow, how would you go about treating it?
- Do you think electronic sensors are the way to go in terms of monitoring animal welfare on farms?
- How feasible do you think electronic sensors are, economically, for farms?

Thank the participants for their time.

Appendix 12

Pilot interview: 001

BH: The only thing is, because I'm having to do it from home I don't have an audio recorder from the University, is that alright? I know it's on the consent form that it would be a University recorder.

001: OK, yeah that's fine, so you'll just do it on your phone or something?

BH: Yeah I've got my tablet out and I'll just put it on the University remote access later.

001: OK cool.

BH: Basically we've kind of gone for a different sort of approach to what we're doing. Because the code, we've realised is going to be quite hard the way we are doing it and I don't know how much I'll be able to do in the year. So we are going to continue with it but just not do it in as much detail I suppose. And then, alongside it we are going to do interviews to see if there are any gaps that you may notice that might identify lameness that aren't currently being recorded. So that's kind of like a parallel project that we're doing to see how we can take it forward. So we just want to kind of interview you to see if you have any sort of ideas of what currently isn't being recorded that could be of use. So, first question is do you think there is an issue with the current mobility score used to identify lame cows?

001: So when you say the currently mobility score you're talking about the 0-3 Dairy Co. one that's used in the UK?

BH: Yeah

001: OK, so I think the things that are good about it are that it's quite straightforward and quite clear what all the scores should mean. So I think it's quite easy to use, quite easy to train people in, and from that aspect it seems quite sort of applicable on farm compared to some scoring systems with much more points in. And it should be pretty easy to define lame vs. non-lame, again as the definitions are very clear and straight-forward. I think, I think its acknowledged in the literature, and its certainly acknowledged, well no, its certainly acknowledged in the literature that there are issues around reliability, validity and repeatability of the score, so, as far as I'm aware its sort of acknowledged that someone ought to go through training on a huge number of cows as well as kind of external validation with an experienced assessor in order to sort of actually be reliable at using the scoring system, and that's not probably what's going on as its used day-to-day. So I think it is a very good score, has the potential to be a very good score, but actually in its day-to-day use is open to huge amounts of error and hence farmers don't necessarily like it and vets don't trust it and students don't believe it. Does that make sense?

BH: Yeah, that's helpful. OK, next question- from your experience of how lameness presents itself in cows what would you say are the most important changes displayed?

001: Can you just repeat the question?

BH: So from your experience of how lameness presents itself in cows what would you say are the most important changes that are displayed?

001: OK, displayed by the cow?

BH: Yeah

001: OK, most important changes that are displayed? So, most important changes that are displayed, because I guess the most obvious changes that are displayed, and so the most easy to identify and so the most I would say reliable and accurate would be a lack of weight-bearing on the leg and to varying extremes. So the easiest lameness to spot, the one that everyone is going to spot, is when they are very minimally weight bearing on that leg, but that's obviously sort of the most severe presentation. Probably, even in the mild presentations there is an obvious difference in weight bearing so I guess that's picked out by the positions of the limbs, the positions of the joints, particularly in asymmetry at the kind of top of the leg and across the hips as they move. So I would say that all comes under kind of lack of weight bearing, and then that stuff is also presented in the stride length of that leg and the tracking up of that affected leg. So I would say those are probably the most important. Yeah, important is a tricky one isn't it? Because in terms of what's actually important is I guess what's most important is whatever the real mild indications of lameness are, and those are probably are still that, but perhaps the shortened stride, but I guess whatever the most important things are, are the ones we are probably all still missing, the really subtle things. So that might come down to it. So yeah that would be the most important in terms of us watching cows, but probably even more important would be really subtle changes in behaviour, so yeah bouts of lying, bouts of activity, standing times to eat, lying times, I imagine those are the things that probably are the most important indicators of the subtle lamenesses that maybe we wish we were detecting better and treating better. Is that reasonable? Is that answering your question?

BH: Yeah, that answers it.

001: So yeah, if it's me watching I would say weight bearing is what I would be looking for as most important but probably they are showing much more subtle behaviours that I don't get an opportunity to see by standing and watching 200 cows go past me.

BH: Yeah, the second question kind of links in to what you've just said, so bearing in mind the information you've been shown and the previous question about lameness indicators, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure lameness? So for example, would you follow the current procedure or would you include other indicators?

001: Yeah OK, cool. So I guess something else maybe I should add in to your very, very first question, sorry for jumping around the place, I was just thinking the other problem with the current mobility score is that we do watch every cow for literally, well for some farms you might get 10 steps, on some farms you might get 20 steps, some you might just get 2 or 3 and that's around the corner and down the hill or something like that. So that's the other massive challenge of mobility scoring is that we are trying to do it in an efficient way. So probably if we could use the same mobility score but we could watch every cow for 20 minutes each like you might a horse, you know if you could walk it backwards and forwards in front of you loads of times then it would probably become better again. But it's also because we have to watch them hurtle past us, so linking on to this question I suppose, time to watch an individual's behaviour, watch them moving would be important. So I think a decent amount of time to watch an individual move would give you a huge amount of information as to whether they were lame or not. But building in to that, then if you're asking about sort of physiological changes, yeah then building into that some of what

I said in the previous question so lying bouts, standing bouts, frequency of lying, frequency of standing, time spent at the feeding space, against a baseline, so having some baseline data for that individual I would have said that would be super powerful- but that's a real dream I feel like. I feel like if we had all that information, you would be really well placed to pick out those changes. In the same way as we are for say heat detection, we have a really nice baseline activity so we know that we can pick out differences in behaviour in that sense because we have the baseline already so I feel you could do the same for lameness if you could gather that information. I guess other sort of types of resources, so for standing and lying would be key behaviours they have to perform but also time spent interacting with luxury things like brushes, I guess, might be an interesting input and then time spent socialising and milling around and doing other activities like grooming others. So information on bouts of activity of all different behaviours I think would be really powerful towards lameness. Does that answer that? I think adding in stuff around, like some of the stuff you were looking for in this, so changes in body condition score and changes in yield, and changes in fertility status, days open and time to take to get back in calf, I think building all that into it would be hugely important too but maybe if we were given any opportunity to look at anything I would probably put behaviours above some of those things, as more useful. If that makes sense?

BH: Yeah, that does make sense. And then finally, how would describe, what would your definition be of chronic lameness?

001: OK, chronic lameness. Yeah I got into a bit of a, when you asked this before, I think I started imploding with thinking about it! I would say already most cases of lameness that I would describe as severe lameness, or easy to detect lameness are already chronic. So any of the more severe lesions that I see are going to lead to chronic changes in gait, chronic changes in behaviour which, at the point of treatment have probably already been pre-existing for some period of time and even after treatment they are going to remain, even with my treatment they may still walk abnormally for some period of time. So I think many of the claw horn lesions, sole ulcers, white line lesions of the kind of more severe presentation would already be chronic so I guess I'm looking at timeframes, so the fact that I think a lot of those would be existing, even with the treatment included, would be existing for say a month of abnormal activity. So I would already describe a lot of those with chronic lameness. But then we also know that we get cows that have those lesions, the lesions cure, but they still walk with what would be described as some of the abnormalities in the scoring system. So they still walk with an arched back, they have strange conformation, they have maybe a dropped fetlock or a dropped heel, turned out toes or something like that, so they carry on walking really abnormally a long time after treatment, and when there's nothing wrong with the feet. So I guess I have two definitions, those would be the ones everyone already acknowledges to be your chronic lame cows but maybe in my mind I think a lot of lame cows I would describe as chronic too. Is that an OK description?

BH: OK so you've got the ones that you say if they've got severe lameness they are already chronic, and then the ones that have lameness, get the lesions cured but still have an abnormal gait?

001: Yeah, I think those I think everyone would currently acknowledge are chronic and probably if I would term something chronic on farm that's what I would term chronic. But actually if we are just talking what lameness is chronic I think that definition should probably also cover the fact that many lesions that we see have a chronic nature to them. Yeah, I think I've been really confusing there, sorry! I think I've given you more than one term, it's like an eskimo needing 15 words for snow I think I need like 3 different types of chronic lameness or something.

BH: Yeah it is quite complicated.

001: And maybe again it comes down to our inability, like maybe you know the mobility score, you know we still have it quite simple, we still score 2s and 3s, maybe we need to expand that into a few more definitions. Maybe a bit like how some cows have cut offs- you know this score for this amount of time or above this limit for this amount of time, you get a particular definition. So maybe we could expand some of that to lameness. So we are still happy that the score 2 definition is right and the score 3 definition is right but actually if you've been a score 2 for 2 months you know, maybe what I'm saying is that maybe a lot of the score 2s are already chronically lame and if you've been a score 2 for 2 months you're now in a new definition and if you've been score 3 you're in a new definition, if you've been a score 3 for a certain period of time you're also of a different definition. So maybe it's sort of around looking at some of the longevity of scores or time periods of time they spend in each score beyond the simple score? And that might add to that definition? Again I feel like I'm really complicating things here but I do feel like that's some of the aspects of chronic lameness that could be reported.

BH: That was helpful. I think that's basically most of my questions.

001: OK, I hope I've been useful there, is there anything you wanted me to expand on or did I answer them as you hoped or is there anything else I could handle better?

BH: I'll just ask one more question, do you think that electronic sensors will be the way to go in terms of monitoring lameness on farm?

001: Again this is something that is quite an area of interest of mine from previous research. I kind of get the feeling that we haven't really come up with the right electronic sensor yet. But there's a lot more research that could be done in that area and certainly with like what we think is the future of dairy farming in terms of size, and the fact that we maybe are currently missing early cases or could do a better job at identifying cows earlier, there must be scope for that to become involved. But I think as yet no study has kind of really found a fool-proof system of being able to sort of also make that practical. Whether it's a force plate or whether its thermal imaging or sort of activity changes, its making that practical in the on farm situation as well reliable, valid and something farmers will buy into and respond to. I think there's loads of scope there but we are a long way off a best system yet.

BH: I think that's everything.

001: I love this topic, it's a great topic! I would be so interested to see, just from what you've laid out, what the other people that you are speaking to, I think just to have a bit more of a big discussion around this topic, and just getting people's thoughts out there on this topic would be hugely interesting. I would love to hear what everyone else would have to say about chronic lameness so I think this is a really interesting topic and I'd be really interested to see. Let me know if I can help you any further with it as well as its really interesting.

BH: I'll let you know how it goes, thank you so much for your help.

Evaluation from Pilot Study 001

Started on the wrong question. Re-familiarise yourself with the 3 main questions and think of ways to integrate the potential questions only if relevant.

- Do you think there is an issue with the current mobility score used to identify lame cows?

Define what mobility score you are referring to, so this question should be changed to-

- Do you think there are issues with the current 0-3 mobility score, used by AHDB Dairy Co. to identify lame cows?

For the question- “From your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?” Maybe this should be split into two questions, one asking about the obvious changes and another that asks about the changes that are the most important, but not necessarily the most obvious.

“Bearing in mind the information you’ve been shown and the previous question about lameness indicators- if you were given data on every aspect of a cow’s behaviour and physiology, what would you look at to measure lameness? For example, would you follow the current procedure or would you include other indicators?” The participant answered this question in reference to resources available rather than aspects of the cow- maybe the question should be refined further or rephrased?

Pilot interview: 002 Evaluation

~~Bearing in mind the information you’ve been shown and the previous question about lameness indicators~~- if you were given data on every aspect of a cow’s behaviour and physiology, what would you look at to measure chronic lameness? For example, would you follow the current procedure or would you include other indicators?

Appendix 13

003 Transcript

BH: The first question is, from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

003: In terms of their, how would I identify it?

BH: Yeah so either their behavioural changes, physiological changes.

003: Ah OK, so the most obvious one would be a limp, so abnormal weight bearing on the affected limb. I tend to look at limb sight and then the arch of their back as well and whether there's any head nodding.

BH: OK.

003: So mainly signs in the legs, occasionally there'd be some milk drop, but I wouldn't expect that to be the presenting sign normally. Occasionally infertility, maybe. A farmer presents a cow that hasn't got in calf and doesn't tell it's lame I guess but you notice that it is.

BH: OK, next question is- if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So, for example, would you follow the current procedure or would look at including other indicators?

003: I guess my slightly academic answer would be, I don't really know because I don't really know what would tell us that, which I guess is part of what you're working on but I would probably look at limb movements and mobility again but then probably would expect milk yield and production to be a bit more important, probably.

BH: OK, yeah. Finally, could you give me your definition of chronic lameness? So how would you define it if you had to?

JR: I guess for me it would be based on time, so an animal that had been lame probably for more than 3 or 4 weeks I would consider chronic. Most people don't treat them very early anyway, so I think if an animal had been lame for more than 4 weeks.

BH: Yeah, OK that's all the questions. Thank you!

<u>004 Transcript</u>

BH: OK, so the first question is, from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

004: Important or obvious?

BH: Probably for you, more important I would say.

004: OK, in terms of being able to identify it?

BH: Yeah.

004: I think the, kind of the cardinal sign is limping. And then the secondary almost, kind of, either drawing your attention to the cow, or confirming that there's lameness are that sort of arched, hunched posture, the nose, the head a little bit lowered as they walk with their nose pointing forwards and a little bit more of a nod as they walk. Speed of movement is, they're usually slower and they grind to a halt much more rapidly, so stopping walking more quickly. And it gets quite confounded as lots of cows are bilaterally lame on both hind legs so then I think when you don't see a limp there's kind of the secondary indicators become more important. But again, the thing that is sort of the cardinal sign for me is the fact that they sort of shuffle, so I describe it as they look like they're wearing stilettos that are too tight for them (not that I grew up in Norfolk or anything!). And they sort of totter along, and it looks quite uncomfortable. So I suppose those are the key things that I look for.

BH: OK, so based on what you've just said do you reckon, what would you say are the current issues with the mobility score? Do you think there are any issues with that based on the changes?

004: Yeah, I think fundamentally different people have different views of what lame is or isn't. So it's a process that's partly based on experience and skill, I think, you know even for myself I'm aware that my judgement can drift a bit over time, so I don't think we've got a, kind of a ground truth, of a way of identifying lameness. I also think the current things that we do depends a lot on the surface that they're walking on, your ability to kind of observe enough material from them, so if you've got a whole bunch coming out of the parlour I think we fool ourselves that we can accurately score their locomotion when they're walking. If we do things like walk them through a foot bath before or after we're trying to score them I don't think that's terribly helpful! I think there are some problems like dermatitis where sometimes they're lame and sometimes they're, presenting as lame and sometimes they're not because I think that particular lesion it's probably really painful but only when it's kind of stimulated, or they knock it, or they accidentally dip their foot in poo or formalin or something and then it really hurts. So, there can be periods where they're walking not too badly with that. The other problem is with this, is the age of the cow can make a difference on how dramatically they present. So, the younger the cow its almost sort of the more they can compensate for it. And also, their body, their joints are freer, and they walk more fluidly. So possibly something that's you know, this is just speculating, but if you had something of equal severity in a younger heifer and a 5 or 6 year old, 6th lactation cow it's probably going to look more serious in the 6th lactation cow because she's already, her body is more worn, and her joints are stiffer, and her posture is less normal and her udders bigger and all those sorts of things. So, there's a little bit of you know, we're not looking, what's it telling us? Because they might be experiencing the same amount of pain but looking differently. So, I just think it's a useful but really blunt instrument for detecting and certainly for understanding lameness and for understanding the cow's experience it tells us just really crudely it's not OK. But beyond that it doesn't tell us anything that's really differentiating between individuals.

BH: OK. So if you were then given data on every aspect of a cow's behaviour or physiology, would you follow the current procedure to identify chronic lameness; or would you do something different, would you look at different variables?

004: So, just putting the kind of the time aside. I think it would be useful, so its that idea of triangulating, so that if you come- you know my old supervisor used to say if you're out on a ship at sea and you're trying to figure out where you are you take different sights from land, and the more sights you take the more accurately you can fix your position. So, when we're sorting trying to understand something about the cow's experience and even just how lame or not lame she is, the more things that we can, the more information we can get, or the more sights we can get, the more we can understand and be certain that we're understanding what's going on with her.

So, I would, but all of that's time consuming and there's a question about whether you can kind of pull that data together. I suppose what we do at the moment with locomotion scoring is we use this kind of heuristic process where you put it all in your head and jumble it around and based on your experience and training and all of that stuff you go "OK, score 2". The more data we put in there, the more variable different people's interpretations of that's going to be. And, and what will probably happen is people will discard the bits that in their experience are less definitive than other bits. So, just conceptually, but if you had a way of, kind of combining more data together in principal it should be helpful in homing in on the right answer, whatever that is. So, I would be interested in more subtle behaviours, I would be interested in things like, kind of just the general body movement and the symmetry of the body, and if there was some way of looking at just, that kind of overall freeness of movement, or not, would be good. I'd be interested in what they're doing in their time budget, in particular. I'd be interested in the information that the person who knows them best says, you know "she's not right today", or "she's in a right old strop today". You know I'm usually in a strop because something's gone wrong in my life and that could reasonably lameness. Then I guess physiology, you know, setting aside all the difficulty of making measures, things like cortisol might be useful, things like inflammatory mediators might be useful to this. So, I think there's a whole bunch of stuff that we could pull together, and I guess, because I know a little bit about what you're doing, the idea that we could pull together easily and quickly lots more measures, to give us a more reliable indicator is worth pursuing.

BH: OK, and finally could you give me your definition of chronic lameness?

004: No! So, I think most of the time when I talk about it I'm talking about, a cow that's severely lame and who's been lame for a number of months. But I think I talk about it that way because that's probably what I think what everyone else is talking about. If I were to take the idea of chronic lameness apart, you know, repeat offenders are probably chronic, it doesn't have to be super severe to be chronic, and I don't know what the transition time is between being acute and chronic because, you know, in theory it could be half an hour after it started being acute. But I think that suggesting it after months of being lame is inappropriate and ridiculous, and that actually we should recognise chronicity much earlier in the process. So, that's not really a definition that's more things to wrestle with!

BH: No, that's still useful! That's all of the questions, thank you!

005 Transcript

BH: So, the first question is- from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

005: Right, OK. The most important changes, well, what do we see? Well the most important change, why do farmers find them I suppose? They're obviously showing pain. Lack of weight bearing, is that the sort of thing you want?

BH: Yeah, just kind of like the obvious or, sort of…

005: Yeah well, OK, early on so obviously you know sort of bearing weight on the affected leg. And then, sort of lack of appetite, looking sort of tucked up, unhappy. And then, sort of losing, going on to obvious condition loss and muscle waste loss as it progresses, I would say, that's probably it. I think its probably fair to say that quite a few of them will then develop the sort of flight response and become less easy to manage sometimes, they sort of know they've got an issue- so herding becomes an issue I think. And yeah, well, milk drops not really fair because we know that happens but I'm not sure that that's an obvious thing. I don't know if that's what you wanted, I suppose you could say the udder goes a bit slack but that's not something I would particularly focus on because they often do keep milking quite well.

BH: OK, yeah. The next question- if you were given, so kind of leading on from that, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So would you follow the current procedure and just continue to mobility score them, or would you at including other indicators? Would you look at measuring different aspects of their behaviour?

005: In an individual cow do you think?

BH: Yeah.

005: Yeah I would probably primarily mobility score them, I think. Mobility score but I would also, but I would also keep examining them, sort of thing, if you know what I mean? So in other words, if they're lame on both legs its sometimes, the mobility score might be a little bit deceiving. So, I would like to get them up, we've had cows before with sole ulcers on both feet that actually you know they walk OK and you lift it up and they've got problems on both. So, chronic cows I tend to like look at every three months regardless anyway. But, I would tend to go primarily on that rather than focusing on other aspects of milk or stuff like that to be honest.

BH: What would you, how would you evaluate the mobility score? So what would you say are the pros and cons of the current system?

005: Pros I guess, pros are it is quick, easy, good specificity but poor sensitivity I think generally. But I still think it's probably the best thing we've got!

BH: Yeah, OK. And would have any, so cons would be…

005: Cons really are the sensitivity I think. It's that we know we are finding cows far too- I did one this afternoon that, you know we do a whole complete package for this farm he rang, as soon as he gets a lame cow he rings us- he found a cow, score 3 cow, hopping Jersey cow, and you know by the time you finish paring out an abscess its underrun after half the sole and we score every 2 weeks there it's not popped up at all on the scoring but there's no way that that cows not had an abscess for probably a couple of weeks at least. So, you know that's an example of poor sensitivity.

BH: Yeah, OK, brilliant. And the final question is- could you give me your definition of chronic lameness?

005: Chronic lameness, yeah, well to me it would be a lameness that's not improving following treatment or not, over time. And that time would be, I don't know, it's really difficult to think, but two weeks? After treatment? Not improving something like that? It's a bit of a stab, I haven't really thought about that one too much, to be honest what I call chronic. I suppose it's one that you see and then you have to see again and normally that interval is unlikely to be in a chronic cow it might be in a fortnight or a month. So, you know it's going to be somewhere between 2 and 4 weeks I suppose still lame, that's sort of chronic.

BH: OK, great that's all of my questions!

005: OK, how, just for interest, how we do it on our records is basically if its scored, if it's got a mobility score 2 or 3, 2 scoring sessions in a row it'll come up as chronic.

But those scoring sessions, you know, could be different intervals apart- ideally, probably a fortnight. Bit like mass cell counts really how they're done by NMR- that's what we based it on.

BH: OK, yeah.

005: Is that alright?

BH: Yeah that's really helpful! Thank you very much for agreeing to be interviewed.

<u>006 Transcript</u>

006: Yeah, in the car so just got to watch directions a little bit but yeah free to talk now.

BH: Alright, brilliant. There aren't that many questions, so it shouldn't take too long. So, hopefully that should be fine. Thank you for agreeing to be interviewed. Would it be possible, when you get a chance, it doesn't have to be today, if you could return the consent form?

006: Yes, yeah that would be fine.

BH: Brilliant.

006: Have you sent it to me recently? I can search through your emails.

BH: I can send you another one today, if you like.

006: Yeah, yeah that would be good.

BH: OK. Yeah, that's not a problem. OK, the first question is- from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

006: Could you repeat the question please?

BH: Yeah, yeah- so, from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

006: Important in what sense?

BH: So, most indicative probably, so like the limp, would it be the limp or would it be the drop in milk yield that kind of thing, lower fertility- what would you say are the most important changes?

006: Yeah, so that's a good question because I always take into account lots of different things and know as much as possible and, yeah it's the degree to which the cow is. There isn't one single important thing, I think that's maybe the important answer. And it has to be a combination of things in my experience in order to arrive at, a) is she displaying the signs of lameness? Consistent with lameness, how severe is it? If there was, if you had to really push me to come up with one single parameter I think it's the descriptive we came up with within, well firstly Becky's lameness score which was then adjusted to make the AHDB mobility score, which is yeah, the cow has even weight bearing on all four limbs.

BH: OK, yeah. The second question is, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So, for example, would you follow the current procedure of just using mobility score, or if you had the chance would you look at including other indicators?

006: I'm not convinced that the reliability of other measures is good enough, so serial mobility scores, ideally weekly or fortnightly mobility scores would be my preferences. Collected by someone who is an experienced, quality assured mobility scorer.

BH: OK, yeah. Finally, could you give me your definition of chronic lameness?

006: Yeah, there's a few definitions. But I like the one month cut-off. I think cows that haven't recovered within one month, they become a bit of a concern. But in a retailer's scheme we've defined it as 3 months but that's, yeah, that's really to give the cow, and the idea is they are a cow that's chronic, that's lame for 3 months. 3 months is to give the farmer, the producer every chance of getting that cow recovered. So, I think that's a very new definition of chronic. We've, within the AHDB partnership we use 5 weeks but that's purely because we took the block off at 4 weeks. I think the 4 week threshold seems to, or 30 days or 28 to 30 days somewhere around there- and it probably needs defining officially. But there have been papers that have defined it in various different ways. But 1 month would be my answer.

BH: OK, so that's all my questions.

<u>007 Transcript</u>

BH: OK, so the first question I have to ask is- from you experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

007: OK, I think the most important changes are the, the outward appearance of the lame cow, like the way that it moves. So the mobility of the cow, not necessarily a change in mobility score but a changing of its gait. A reduction in feeding time. The change in lying time behaviour, so I'm not necessarily saying a reduction or increase in lying time, I'm just saying a change in its characteristics or its normal lying behaviour, if that makes sense. So we sometimes get an increased number of bouts, change in bout duration but I think just change from the norm is probably what I would say there. Potentially a drop in milk yield, but not always. And… yeah that's a good start.

BH: Yeah, that sounds good. Would you be able to give me your pros and cons of the mobility score? So how would you evaluate the mobility score?

007: OK, the pros is that it's a good, blunt instrument for identifying score 2 and score 3 cows, particularly for farmers who don't use the mobility scoring system terribly often. It's good for highlighting cows that need prompt treatment. It's not very sensitive, and also I'm not sure it detects changes in lame, foot pathology early enough because we obviously we now know, with latest research that the aetiology of lameness has started well before we get a cow changing from a score 1 to a score 2, so it's not picking up things early enough would be my comment. It's not sensitive enough but it's also not specific enough either.

BH: OK, brilliant. So if you, kind of leading on from that, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So for example, would you follow the current procedure of using a mobility score or would you look at including other indicators? So in an ideal world, if you could get the farmer to gather all this data what would you look at?

007: When you say chronic lameness, are you using that in the way, I'm sure you mean, chronic lameness as in a lameness that's been going on for a long time rather than a severe lameness?

BH: Well that kind of comes down to your, so the question after this one would be "what's your definition of chronic lameness?" So we are kind of recognising that everyone has slightly different definitions of chronic lameness.

007: Because in my mind, a cow that has been even a mild score 2 for 6 months, is a chronically lame cow. Whereas sadly the industry accepted definition for the chronically lame cow is a severely, score 3 that has been a score 3 for a long time, which I don't. This is the problem, we know chronic to be something that's been a long time in duration whereas that's not the understanding for most farmers. Something chronic in their heads is something that's bad. So, that hasn't really answered your question!

BH: You can change it to just what would you look at to measure lameness? If that's easier for you to sort of tackle? So how would you, would follow the same procedure just mobility scoring them to detect lameness or would you…

007: I think I would, but I think I would say with regular mobility scoring rather than with just sporadic mobility scoring. But I would say that, we're very lucky that we've got 8 guys down here who are trained to mobility score and know exactly, and are very harsh on their mobility score. And that's what you need, you don't want, you want a really… I want to say someone who is a registered mobility scorer, but I'm afraid until, I'm yet to be convinced that there are a lot of people on that list that I think will say one thing and do another. Whereas I know our guys, for example, will do it as they see it. So I think strict, regular mobility scoring.

BH: OK, brilliant. So going back to the question how would you define chronic lameness? What would be your definition?

007: My personal definition would be a cow that has been a score 2 for longer than a month. Not terribly scientific but I know that yeah... I'm just trying to think, looking back at Hetty's work on the blocks and things, I think its score 2s something like that. No I think let's stick with that. I think, that's for me anyway.

BH: OK, brilliant. That's all my questions.

008 Transcript

BH: So, the first question is, from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow? So what are the things you kind of notice or what are the most obvious changes. That kind of thing.

008: I think first of all, reduced weight bearing on one limb is what I always look for. So, yeah any change from her, from a normal mobility, so usually a quickened stride when the weight is on the lame limb, so the flight time of the other leg reduces that's probably what I look for. But then as it gets more and more chronic, then probably that its falling back in the herd and just being at the back of a group of animals that's walking but that's really secondary I'd say.

BH: Yeah, OK. Would you be able to give me your evaluation of the mobility score? So what are the pros and cons of it?

008: So, I like the mobility score because it's, it really looks for that, I suppose it's the way I'm trained around mobility scores, to look at reduced weight bearing on one leg. Its, it's very easy to explain and easy to do, I think there's a lot of discrepancy at the more milder end of lameness where a cow is probably very, very early lame. Some people put them as a 2 straight away, I know people would argue that not quite, not quite lame yet. It's really that, just that discrepancy between early lame cows is a problem with it. And the other one is, if, if you're doing it out of the parlour then groups of animals running out of the parlour all at once can be very difficult to properly score each one. But that's more just a trying to do, watch too many, score too many cows at once I suppose.

BH: Yeah, OK. The next question is, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So, would you follow the current procedure of mobility scoring, or would you look at including other indicators?

008: So if you're just looking at chronically lame cows for improvement?

BH: Yeah.

008: Yeah, mobility score I think is a good one for them because a score, once a cow is a score 3 then I suppose you're looking for any, you're looking for her to walk quicker, walk easier. And also, come back into a social place in the herd, because if she's dropped to the back of milking because she's so lame then hopefully, hopefully at some point she'll recover and get back up the pecking order. To be able to stay at the feed face whilst the stronger cows are there, rather than being pushed off. Yeah those are probably the ones I'd look for, does that kind of make sense?

BH: Yeah, that answers that. And finally, could you give me your definition of chronic lameness? So how would you define it?

008: I would say a cow that's been lame for a while. I suppose chronic is a time frame isn't it and it's very difficult to put a time on it but you could go anything for more than, if a cow's been lame for more than 2 weeks then she's getting towards chronic. Yeah, or a cow that keeps becoming lame and curing and then alternating between lame and cure. Probably either of those things. It's really about the time frame, I don't consider severity, like a really severely lame cow to be chronic is what I'm trying to get at.

BH: That's all of my questions!

<u>009 Transcript</u>

BH: So, the first question is- from your experience of how lameness presents itself in cows, what would you say are the most important changes displayed by a lame cow?

009: Ooo, this is going to be like one of those, sort of, yeah good question, a question that you definitely have to quickly wrap your head around, don't you. So, most important changes in a cow associated with lameness…

BH: Yeah.

009: Oh, this is just where I end up asking, thinking of a whole load of other questions- it's like important in terms of what? I guess the, so this is going to… yeah shall I just talk away and then you can just…

BH: Yeah go for it!

009: So I guess the sort of the impacts on the cows themselves, impaired mobility and the welfare issues associated with that. And then, impacts in terms of their production and milk yield, fertility, culling, etc. So, then we've got that, I guess that kind of goes on to then to impacts on economics on farm etc. Impacts on behaviour and you know including sort of feeding behaviour as well as lying behaviour, social hierarchy etc. Sorry that's quite a few different important ones!

BH: No that's useful! The second question is if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So for example, would you follow the current procedure of just mobility scoring them, or would you look at including other indicators?

009: Hmm. So, I guess classically you think just mobility score and use that as your system for monitoring lameness. I think, you know clearly from your project, it makes an awful lot of sense to incorporate looking at other behaviours and parameters as well. Do you want me to suggest a couple of those which I think would be relevant?

BH: Yeah, yeah give your ideas. So it's kind of like in an ideal world if you could access any data what would you like to look at to identify lameness?

009: So, I think it would, well milk yield would be a useful one, body condition score would be useful, and it would also be useful in terms of the sort of lying times, but you know behaviour aspects around that, feed intakes, always be a good one wouldn't it feed intakes. Yeah, they're probably the most relevant ones that I can think of straight off the top of my head.

BH: Yeah. Would you be able to quickly sort of evaluate the mobility score? So what do you think are the pros and cons of it?

009: Pros- is that, and are you specifically talking about the AHDB you know mobility score that we use in the UK?

BH: Yeah

009: Pros I think is that it's quite simple and accessible you know to anyone and everyone to use, well to some degree. It's you know, I guess being sort of a 3, 0-3 scoring system, yeah, it's relatively simple to use from that perspective. I think the clear cons of it is just the subjectivity and different people using it in slightly different ways, and then that'll all be related to training etc. I think another difficulty which, yeah actually because we've just been doing a load of mobility scoring this morning, it's the usual sort of bilateral lameness and different interpretations by different people, which I guess then sort of falls back into subjectivity of the scoring system.

BH: Yeah, and finally could you give me your definition of chronic lameness?

009: Good one! Bet you're going to get a whole variety for this aren't you!

BH: So far no one has answered this question the same.

009: Yeah, that's, that's a really, that's going to be a flipping difficult one to get it down. Because that again is just going to be so subjective.

BH: Yeah!

009: So, maybe I'll talk about this a bit actually from a research perspective, because that's a lot more the angle that I've always come at with lameness and in my research we were dealing with weekly mobility scores. So, when we were looking at sort of, you know I guess part of this is sort of chronic vs. recurrence as well. And you know a lot of the research I guess we sort of, because you're looking at weekly mobility scores, do you know from one week to the next that that's the same case or not? How does that case last for? And how do you define that? So I think from a, yeah certainly from my experience of dealing with mobility scoring data and defining that its, it's really difficult to do. I guess, are you looking at this in terms of definitions around whether they've received treatment or not and? Or this just more around sort of mobility scoring? Because I guess your research is more just looking at mobility scoring isn't it?

BH: It's kind of just been to get people's initial response, like how people would initially respond to defining chronic lameness. So whatever you kind of would think when you hear the term chronic lameness, how would you identify cows being chronic? So it's kind of whatever ideas you've got, it's quite an open ended question. So we haven't got any ideas about how we want it to be answered.

009: Right OK, and sort of how you're going to interpret that and narrow that down.

BH: Yeah.

009: Yeah OK, if I had to put a threshold on it then I would probably say, I'd be looking at 3 or more consecutive weekly mobility scores.

BH: Yeah, yeah that works!

009: That would be my sort of vague but off the top of my head threshold!

010 Transcript

BH: So, the first question is- from your experience of how lameness presents itself in cows, what would say are the most important changes displayed by a lame cow?

010: Tracking.

BH: Yeah.

010: Speed. Probably then I'm looking at arched back. And, and also, I don't know what the technical term is but swinging in and swinging out, you know from the rear?

BH: OK, yeah.

010: Adduction and whatever the other one is. I'd probably look at that higher up actually, the swinging in and swinging out before back arch.

BH: OK, yeah.

010: And then probably head bob.

BH: Yeah.

010: That's probably my top, top ones.

BH: OK, brilliant. The next question is, if you were given data on every aspect of a cow's behaviour and physiology, what would you look at to measure chronic lameness? So would you follow the current procedure of mobility scoring them or would you look at including other indicators?

010: I think yeah, if other indicators were available I would probably look at lying times.

BH: Yeah.

010: Mobility scoring would still be my number 1, but I think lying times would be my other one. I don't think I would, I would have much awareness for other sort of tools available.

BH: Yeah. And the final question is would you be able to give me your definition of chronic lameness?

010: Chronic lameness. I think chronic lameness is a cow that's unable to walk normally.

BH: Yeah.

010: She's displaying severe symptoms of pain via shortened strides, head bob, arched back, uneven gait and speed.

BH: Yeah.

010: I think that would be, and obviously asking questions, so she'll have been displaying that for a sustained period of time.

BH: Yeah, would you- do you have a specific time that you would kind of be looking at for these symptoms or?

010: Do you mean how long would she have been, how long she would have been lame to get to that chronic lame stage?

BH: Yeah, yeah.

010: That's sort of quite difficult because some cows go lame really quickly don't they.

BH: Yeah.

010: I suppose it depends on her previous history, so if she's got a previous history of chronic lameness she could go chronically lame you know from one week to the next. If it's a new case of chronic lameness then it could have crept up over say 2 months, where she started off perhaps a score 1, and then developed a score 2, and then ended up being a chronically lame cow at score 3.

BH: Yeah.

010: Yeah I think that's probably…

BH: OK, brilliant, that's all of my questions!

Said after recording that it would depend on how the cow is handled- could be an interesting thing to look at.